

INDUSTRIAL ABATEMENT – AIR MANAGEMENT

1976



**Ministry
of the
Environment**

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MINISTRY OF THE ENVIRONMENT

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

1976

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INTRODUCTION

The *Industrial Abatement-Air Management* manual has been prepared to assist the trainee and the instructor to achieve the objectives of the *Industrial Abatement-Air Management Course*, which has been developed to familiarize new personnel with the air management aspects of Industrial Abatement, and to increase the efficiency of provincial officers involved with those duties.

The course consists of three parts, each of approximately five days duration. In order to qualify for the award of a certificate, the trainee must have achieved a pass mark of at least 60 per cent in the examination set at the end of each part of the course.

This certification course is one of a series of courses, seminars and workshops regularly offered by the Ontario Ministry of the Environment, Training and Certification Section, in Toronto.

March, 1976

*Training & Certification Section
Personnel Services Branch*

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SUBJECT:

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

TOPIC: 1

INTRODUCTION

OBJECTIVES:

The trainee will be able to:

1. List the three forms of air contaminating processes; combustion, vaporization and mechanical attrition and briefly explain what is meant by these terms;
2. Define or explain the following: Smoke, fume, vapour, mist, gas, calcination, sublimation, distillation, organic gas, inorganic gas;
3. Explain why nitrogen oxides, sulphur oxides and carbon monoxide are undesirable constituents of the atmosphere.

INTRODUCTION

1.1 Ever since man has attempted to satisfy his basic needs by seeking ways to manipulate his environment more efficiently, one form or another of air pollution has been present to plague him. The various periods of human history, the ages of fire, copper, bronze, iron and atomic, testify to the fact that man has always engaged in air polluting activities.

In 1257 AD, the smoke of Nottingham was so bad that Queen Eleanor, the wife of Henry the Third, was compelled to move to Tutbury. In 1306 AD, a royal proclamation prohibited the use of coal in certain furnaces, with a Commission appointed to punish offenders. The first offence being fines, second, demolition of the furnaces, and the third offence execution, and history records one such execution.

One of the first recommendations to control smoke was by Thomas Owen, who in 1595 AD proposed to transport smokeless coal from London to South Wales.

In 1661 AD coal smoke was so bad that the diarist, John Evelyn, in writing about London stated "the weary Traveller at many Miles distance, sooner smells, than sees the City".

Initially these air polluting activities were isolated in small settlements and towns and were treated as individual cases of smokes and fumes, affecting only those living close to the sources of air pollution, but with the impact of the industrial revolution in the eighteenth and nineteenth centuries,

cities grew and air pollution nuisances increased in frequency and complexity, giving rise to total pollution of entire metropolitan air spaces.

Thereafter, in England the smoke problem was attacked on a community basis, the first anti-smoke ordinance being adopted in 1847. In the U.S.A., the first was in Chicago in 1881, and in Toronto, 1907.

It was not until the twentieth century that the resources of science and technology began to be applied to the control of municipal air pollution with any degree of concentration, when considerable knowledge of the nature and control of air pollution emerged. Even so, in the early part of the century control programmes were designed to control visible emissions, with the emphasis on smoke.

It is only perhaps in the last twenty years that air pollution control legislators have become farsighted enough to tackle effectively the more sophisticated problem of air pollution; the pollution which often cannot be seen. In this period the problem of air pollution has been subject to many professional disciplines, including engineering, law, public administration, economics, medicine and most of the major fields of pure and applied science.

General Sources of Air Pollution

1.2 To the extent that there is a constant and varied activity taking place on the surface of the earth, the general concept of air pollution includes a large variety of specific air pollution problems. These can be divided into two broad classes, Natural and Man-Made.

1. Natural Pollution

1.3 Natural sources of air pollutants include:

wind blown dust
volcanic ash and gases
ozone from lightning and the ozone layer
esters and terpenes from vegetation
smoke, gases and fly ash from forest fires
pollens and other aeroallergens
gases and odours from natural decomposition
natural radioactivity

Such sources constitute background pollution and that portion of the pollution problem over which control activities can have little, if any, effect.

2. Man-Made Pollution

1.4 Such pollution is a by-product of a civilization which has become dependant on its technology in industry for its survival. Modern civilization has progressed by the replacement, substitution or extension of manual or natural activities, such as those found in primitive economies, with mechanical devices and synthetic or fabricated materials. These involve industrial techniques, vehicular, marine and aerial forms of transportation, mass communication, rapid distribution of raw materials and manufactured products, centralization of energy and heat sources, together with all services necessary to the construction and maintenance of an urban community. Five main classes of pollutants, particulates, carbon monoxide, hydrocarbons, nitrogen oxides and sulphur oxides, are summarized nationally for the year 1970 in Table 1-1.

TABLE 1-1

EMISSIONS IN TONS - 1970NATIONWIDE EMISSIONS OF AIR POLLUTION

Emission Source	Particulate Matter	Sulphur Oxides	Nitrogen Oxide	Hydrocarbon	Carbon Monoxide
<u>Industrial Sources</u>					
Primary Iron and Steel Mills	152,911	-	-	-	45,772
Iron and Steel Mills	10,594	-	-	-	16,090
Metallurgical Coke	10,564	40,330	162	16,891	5,101
Primary Aluminum	35,260	23,665	-	-	-
Primary Copper and Nickel	68,105	4,420,592	-	-	-
Primary Lead and Zinc	7,565	115,515	-	-	-
Petroleum Refineries	1,300	32,574	3,876	65,722	464,766
Cement Industry	247,682	-	-	-	-
Lime Industry	53,902	-	-	-	-
Nitric Acid	-	-	11,234	-	-
Sulphuric Acid	-	54,565	-	-	-
Kraft Pulp Mills	86,375	16,260	-	-	227,122
Sulphite Pulp Mills	-	149,041	-	-	-
Asbestos	79,962	-	-	-	-
Stone	109,914	-	-	-	-
Sand and Gravel	291,150	-	-	-	-
Natural Gas Processing	-	592,889	-	-	-
Grain Handling	83,495	-	-	-	-
Grain Mills	4,241	-	-	-	-
Dry Cleaning	-	-	-	28,858	-
Other	76,628	-	-	-	-
Additional	80,500	-	-	-	-
<u>Fuel Combustion in Stationary Sources</u>					
Utilities and Power Generation	220,569	478,957	175,681	4,278	8,176
Industrial and Commercial	133,249	890,547	209,174	40,879	27,978
Private	37,130	215,951	46,386	23,320	66,919
<u>Transportation</u>					
Gasoline-powered Motor Vehicles	31,123	18,669	621,964	1,969,549	12,853,913
Non-Highway Use of Gasoline	3,380	2,026	67,576	213,995	1,396,587
Gasoline Marketing	-	-	-	127,172	-
Diesel-powered Motor Vehicles	3,650	7,581	103,887	10,389	63,172
Railways	9,017	34,439	21,635	13,170	18,464
Marine	11,113	108,352	18,768	6,425	8,140
Aircraft	3,956	922	3,040	17,893	13,687
<u>Solids Waste Disposal</u>					
Municipal Incinerators	11,223	2,788	3,729	2,788	65,256
Industrial Incinerators	27,039	4,102	20,886	26,853	44,753
Apartment Incinerators	7,881	260	1,577	7,884	10,511
Wigwam Burners	43,887	-	-	43,887	515,369
<u>Miscellaneous</u>					
Structural Fires	7,396	-	-	7,396	14,792
Slash Burning	62,611	-	7,368	14,736	184,165
Surface Coating	-	-	-	180,000	-
Forest Fires	357,354	-	42,048	252,252	1,261,252
TOTAL	2,370,726	7,210,025	1,358,991	3,074,337	17,311,985

Source: Environment Canada, Technical Appraisal Report
E.P.S. 3-AP-73-2

1.5 These activities can be reduced to three forms of air contaminating processes:

1. Combustion
2. Vaporization
3. Mechanical attrition

1. Combustion

1.6 The combustion of fossil fuels and waste materials for heat, steam and electrical energy is applied universally to provide warmth, metal melting, motive power, food processing, incineration of waste materials, baking, tempering, curing and many other processes. The products of combustion, smoke and gases, comprise contaminant plumes typical of all cities.

Smoke

1.7 Smoke is the visible effluent resulting from incomplete combustion. It consists mostly of soot, fly-ash and other solid or liquid particles less than one micrometre in diameter. Depending upon the composition of the fuel or materials being burned and the efficiency of combustion, various volatilized gases and organics such as aldehydes, various acids, sulphur oxides, nitrogen oxides and ammonia may also be emitted. Due to the low vapour pressure and slow settling properties of the particles, the smoke may be carried considerable distances from the source and many submicrometre particles will be permanently dispersed in the atmosphere.

Smoke will vary in colour, but will be generally observed as grey, blue, black, brown and white, and sometimes yellow, depending upon the conditions under which certain types of fuels or materials are burned. The colour of smoke is generally a fairly

good indication of the type of combustion problem encountered.

Smoke which is grey or black in colour may indicate that material is being burned with insufficient air or inadequate mixing of fuel and air.

White smoke usually results when combustion is cooled by excess drafts of air, or when the materials being burned contain excessive amounts of moisture.

Brown or yellow smoke may result from the burning of semi-solid tarry substances such as asphalt or tar paper, resulting from inadequate temperature and mixing.

A blue colour or light blue colour is often associated with the burning of domestic trash consisting mostly of paper or wood products. The light blue colour seems to stem from the fine particles of pyroligneous acid due to sulphide treated paper and wood tar constituents. The blue plume contains little or no carbon or soot particles.

2. Vaporization

1.8 Vaporization, or volatilization, is a by-product of a large variety of chemical and manufacturing processes which induce physical changes in substances through the application of heat and pressure, thereby causing some component materials to vaporize in the atmosphere. Vaporization includes the evaporation of volatile materials at normal atmospheric temperatures and pressures; fuming as a result of induced temperatures; and decomposition of organic materials as a result of natural processes. Some materials with high

vapour pressures will evaporate within the range of normal atmospheric temperature and pressure conditions. These include petroleum derivatives, such as gasoline and fuel oil, which are consumed by the entire economy, from motor vehicles and fuel oil burning to organic solvent usage.

Fumes

1.9 In air pollution control, fumes are referred to specifically as "condensed fumes". These are minute solid particles generated by the condensation of vapours from solid matter after volatilization from the molten state, or may be generated by sublimation, calcination or chemical reaction when these processes create airborne particles. Fume particles are generally less than one micrometre in diameter and will behave like smoke. Fumes will more commonly consist of metals and metallic oxides and chlorides. Also contained in the fumes are common solid particulates such as fly-ash, carbon, mechanically-produced dust and gases such as sulphur dioxide. The fumes principally emitted, however, are actually dusts condensed from the more volatile elements in the metals melted such as zinc, sulphur, lead and others.

The provincial officer will probably be mostly concerned with metallurgical fumes. The metallurgical fume will consist primarily of the metallic oxide which is driven from the melting surface when metal is heated to the molten state. Metals such as copper and bronze with relatively high boiling temperatures, as compared to their melting and pouring temperatures, do not readily volatize and do not constitute an air pollution problem. Copper and tin, for

example, have boiling temperatures above 2,200°C, but are poured at temperatures at about 1,090°C.

Some metals may contain alloys with extreme differences in volatility. Copper-based alloys such as yellow brass, manganese bronze, brazing spelter and various plumbing metals contain from 15 to 40 per cent zinc, the boiling temperature of which is around 1,200°C. Since the metal must be heated to melt the copper which has the highest pouring temperature, a portion of the zinc will be brought to its boiling point and will volatilize. Copper alloys with high zinc contents may lose from 2 to 15 per cent of their zinc through fuming.

When vented to the atmosphere, fumes may have the appearance of smoke. However, all of the sources of fumes may not be practically vented in a large-scale foundry operation, so that fumes in the vicinity of a plant may appear as a haze or a cloud emitted from factory monitors or windows.

Other processes which will produce fumes include calcination, sublimation and distillation.

Calcination consists of heating, roasting or smelting to decompose minerals. Calcination is commercially applied in the manufacture of glass and mineral catalysts through the heating of materials such as sand and limestone. It is variously employed to remove moisture or a volatile constituent by such methods as heating limestone to form carbon dioxide gas and calcium oxide, or to reduce minerals by oxidation.

Sublimation is the process in which a solid substance is converted to a gas without a change in

composition and without first going through the liquid state. Iodine, carbon dioxide (dry ice) and many metallic and nonmetallic crystals are examples of sublimed materials. Sublimation of these materials may be accomplished by lowering the pressure, raising the temperature or by changing both temperature and pressure.

Distillation is a cycle of vaporization and condensation in which a liquid is converted to a vapour and condensed to a liquid. Distillation is generally employed to purify a liquid or to segregate components according to relative volatility.

Vapours

1.10 A vapour is the gaseous phase of a substance which at normal temperature and pressure is a liquid or solid.

The most important vapour air pollution problem is that which results from the evaporation of petroleum products, such as the unburned gasoline vapours in automobile exhaust. Gasoline vapours also originate from processes in which volatile products are maintained in storage tanks and from the operation of pumps, compressors and blowers required for moving liquid gas streams.

Another principal source of vapours originates from the consumption, marketing and manufacture of paints and other coating products containing organic solvents which are used to dilute or extend surface coatings. These are released to the atmosphere upon application.

3. Mechanical Attrition

1.11 These processes consist of crushing, grinding, drilling, demolishing, mixing, batching, blending, sweeping, sanding, cutting, pulverizing, spraying, atomizing of material, etc., which either directly or indirectly disperse particulates such as dusts and mists into the atmosphere.

Dusts

1.12 Dusts are produced from virtually every human activity as well as from the natural environment. Some dusty industries include mineral earth processors such as ceramic and cement manufacturing, calcining, and wood-working and feed and flour industries.

Dust particles mainly exceed one micrometre in diameter and are readily controlled by centrifugal separators, cloth filters and electrostatic precipitators.

Mists

1.13 Mists consist of liquid particulates or droplets, less than the size of raindrops, such as fog, and are formed by condensation of a vapour or atomization of a liquid by mechanical spraying. Mist droplets may contain contaminant material in solution or suspension. The impregnation and coating of building materials with asphalt or the manufacture or heating of asphalt at batch plants may produce hazes or fogs containing drops of liquid asphalt. Paint spraying operations emit liquid particulates containing organic solvents, pigments and other materials. Mists may

also be emitted from control devices such as cyclones and scrubbers, using a liquid air cleaning medium. Acid particulates, such as chromic and sulphuric acid produced from chrome plating operations, may form mists when exhausted to the atmosphere.

Air pollution is usually the unintentional result of the conduct of some activity which emits undesirable substances into the air in either one, or a combination, of the following states:

1. Aerosols and particulates
2. Organic gases
3. Inorganic gases

1. Aerosols and Particulates

1.14 A particle is any dispersed matter, solid or liquid, in which the individual aggregates are larger than single molecules, but smaller than about 500 microns in diameter. A continuous spectrum of sizes occurs among the particles in the atmosphere, with corresponding gradations in physical and chemical properties. Figure 1-1 illustrates the size range and some common characteristics.

1.15 Variations in size confer different physical and chemical properties on the particles. It is important, therefore, to be familiar with the scale and size ranges of common particulate substances and corresponding changes in properties. For example:

- * A micron (micrometre) is equal to 1/1000 of a millimetre, or 1/25,000 of an inch

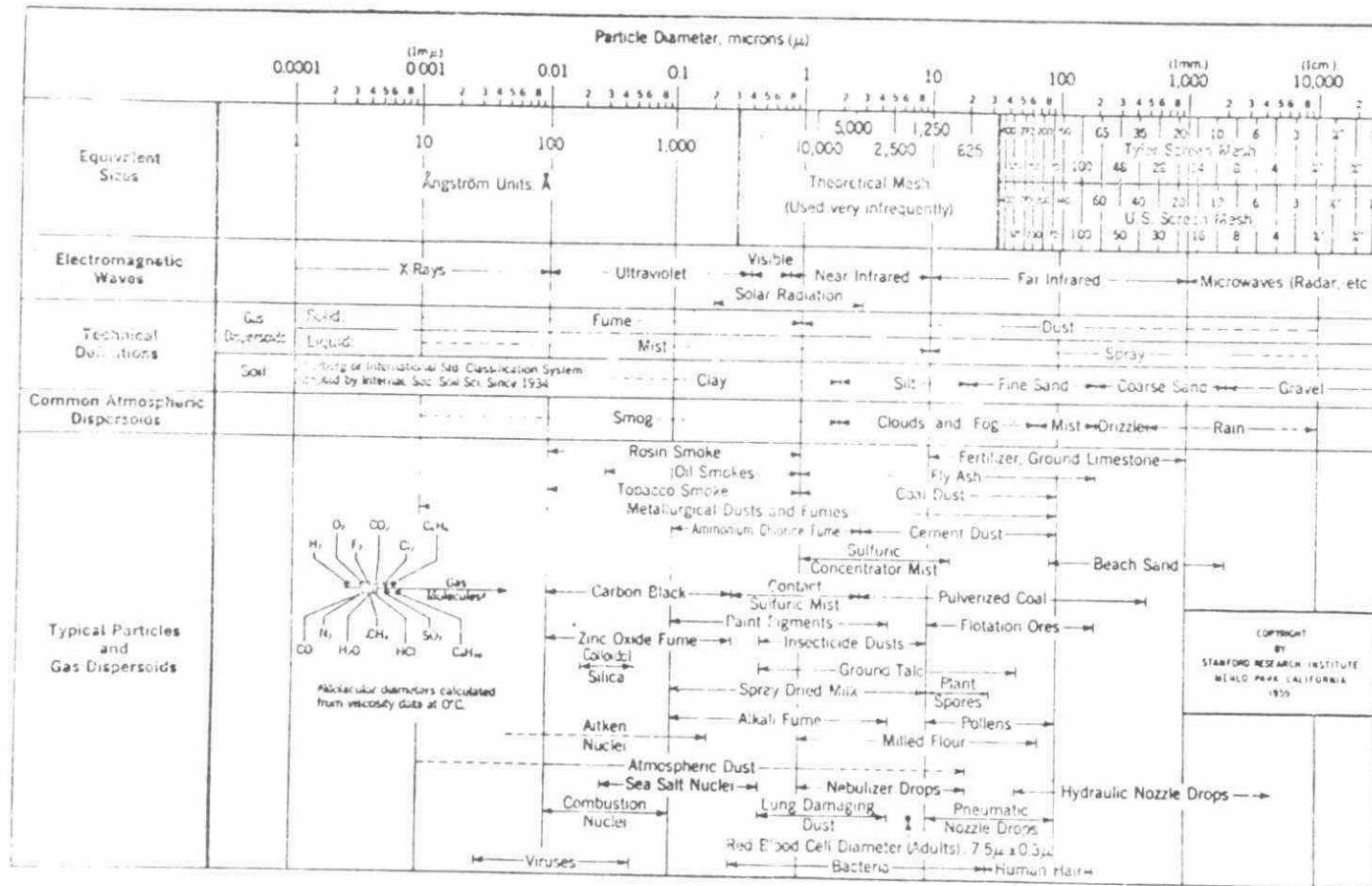


Figure 1-1 CHARACTERISTICS OF PARTICLES AND PARTICLE DISPERSOIDS.

SOURCE: SHEEHY, ET. AL.

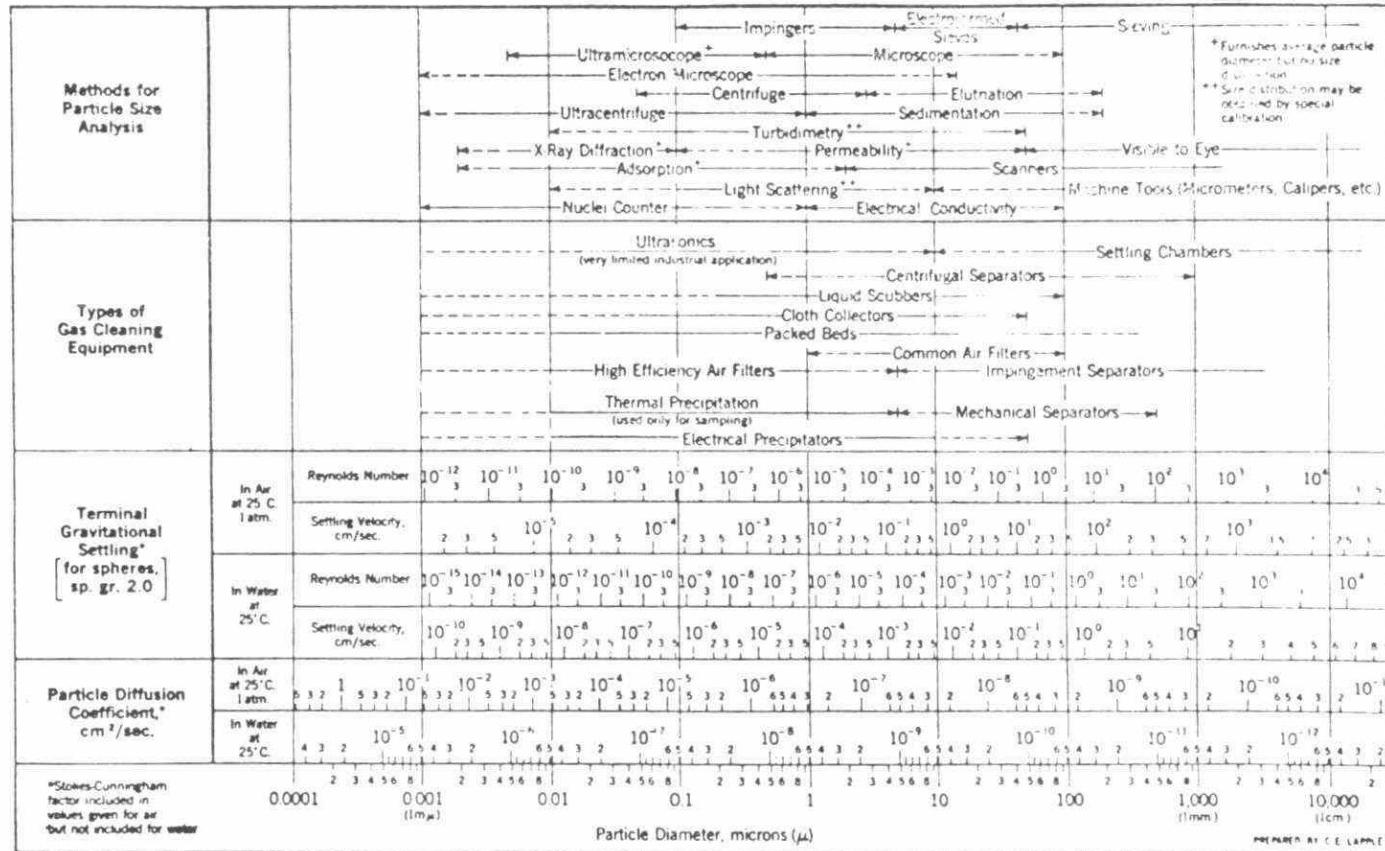


Figure 1-1 CHARACTERISTICS OF PARTICLES AND PARTICLE DISPERSOIDS. (continued)

- * Viruses are between 0.01 and 0.1 micron in size
- * Bacteria are between 1 and 25 micron in size
- * Fog droplets are between 5 and 60 micron in size
- * Raindrops are between 400 and 5,000 micron in size
- * Particles approximately 10 micron in diameter are barely visible to the naked eye

Aerosols are usually particles which range in size from 10 microns to something less than 0.01 micron. Most aerosols are considered to be less than 1 micron in diameter.

1.16 Particulates are responsible for two basic types of air pollution problems:

- (a) Soiling, corrosion, injury to clothing, property and crops as a result of deposition
- (b) Adhesion of particulates to respiratory tissues with possible physiological impairment or damage. Particulates may include toxic substances, possibly carcinogens and radioactive materials.

1.17 Polluting particles are composed of a variety of substances originating from the myriad activities conducted by man. Because their size and, to a lesser degree, their physical state influence their behaviour so greatly, they are commonly identified by the appearance and behaviour of the emissions in which

they are contained. For example:

- * Smoke describes unburned carbonaceous particles mostly 1 micrometre in diameter produced as a result of combustion.
- * Fume indicated the solid particles under 1 micrometre in diameter that are formed as vapours condense or as chemical reactions take place. Fumes are emitted by many industrial processes, including metal smelting and refining, distillation, and removal of solid impurities by boiling liquid materials and condensing the vapours.
- * Dust is a more general term than fume. When solid particles are more than 1 micrometre in size they are generally referred to as dust. Dust may be formed by natural processes or in innumerable mechanical operations conducted at industrial and agricultural facilities.
- * Mist consists of liquid particles up to 100 micrometre in diameter. They may be released in such industrial operations as spraying and impregnating, or formed by the condensation of vapour in the atmosphere. As mists evaporate, more concentrated liquid aerosols may be formed.

1.18 Aerosols tend to remain suspended permanently in the air and are usually emitted either in aerosol form or evolve from the fracturing or decomposition of large particulates, or they form in the air from the condensation and nucleation of gaseous contaminants. They may be organic or inorganic in composition, and may be liquid or solid. The smaller the aerosols the

more they behave like a gas. Aerosols, therefore, are not as readily deposited as the particulates and may be inhaled and exhaled with air. Aerosols are also important for their ability to reduce visibility through the process of light scattering.

Gases

1.19 A gas is a non-coherent state of aggregated matter, i.e., a fluid of freely-moving molecules tending to expand infinitely and to diffuse and mix readily with other gases. As pollutants, gases include a large variety of inorganic and organic gases which may have noxious, malodorous, toxic or corrosive effects, or which may have an effective smog-producing potential.

2. Organic Gases

1.20 Organic gases consist entirely of compounds of carbon and hydrogen and their derivatives. These include all classes of hydrocarbons (olefins, paraffins, and aromatics) and the compounds formed when some of the hydrogen in the original compounds is replaced by oxygen, halogens, nitro or some other substituent groups. The latter are the hydrocarbon derivatives.

The principal origin of hydrocarbons is petroleum, and the principal sources of emission of hydrocarbons and their derivatives are those related to the processing and use of petroleum and its products. Hydrocarbons are released to the atmosphere during the refining of petroleum, during transfer and storage of petroleum products, and during the use of products such as fuels, lubricants, and solvents. Derivatives of hydrocarbons can also be released into the atmosphere in connection with these processes and in connection with their manufacture and use. They can even be formed in the atmosphere as the result of certain photochemical reactions.

Hydrocarbons

1.21 The most important source, by far, of emission of hydrocarbons is the use of gasoline for the operation of motor vehicles. This source alone accounts for the major part of the total emission in heavily populated areas. Except for about 2% of the total, the balance of the hydrocarbon emission are divided between the petroleum industry and industrial and commercial users of organic solvents.

Two groups of hydrocarbon compounds are of great importance in air pollution: (a) the olefin or ethylene series and (b) the aromatic, benzenoid or benzene series.

(a) Olefins

1.22 The olefins are a group of unsaturated carbons. (Unsaturated compounds react easily with other chemicals.) Most olefins in small concentrations appear to have no direct effect on animal life, although some cause a general reduction in plant growth. In addition, olefins take part in photo-chemical reactions with nitrogen oxides and several other classes of compounds.

(b) Aromatics

1.23 Included in the aromatics are a number of compounds believed or known to be carcinogenic (cancer-producing). The most potent of these is benzpyrene (often written benzo(a)pyrene or 3, 4 benzpyrene). A primary source of these carcinogens is the incomplete combustion of organic materials. In fact, most polluting hydrocarbons are discharged into the air by incomplete combustion. And the

major source of this kind of contamination is the burning of gasoline in automobiles.

Hydrocarbon Derivatives

1.24 The greatest part of hydrocarbon derivatives emitted to the atmosphere results from solvent uses such as surface coating, degreasing, and dry cleaning, and other industrial and commercial processes. The balance is included in the products of combustion of various fuels and of the incineration of refuse. The substituted hydrocarbons emitted to the atmosphere by industrial and commercial use of organic solvents include oxygenates, such as aldehydes, ketones, and alcohols; organic acids; and chlorinated hydrocarbons. Most hydrocarbon derivatives associated with surface coating are oxygenates whose presence can be related either to the solvent itself or to the products of the partial oxidation involved in the drying of the coated objects. The hydrocarbon derivatives associated with degreasing and dry cleaning are mostly chlorinated hydrocarbons. The derivates associated with combustion, either of fuels or of refuse, are products of incomplete combustion and are almost entirely oxygenates. Thus, the composition of atmospheric emissions of hydrocarbon derivates is currently about one fourth to one third chlorinated hydrocarbons and two thirds to three fourths oxygenates.

Hydrocarbons and their derivates are important because of their ability to participate in the atmospheric reactions that produce effects associated with photochemical smog. The most reactive group, the olefins (unsaturated hydrocarbons), can react with nitrogen dioxide to produce plant damage, eye irritation, visibility-reducing aerosols, and oxidants or ozone. Paraffins

(saturated hydrocarbons) can also react with nitrogen dioxide to produce all these effects except plant damage. Aromatic hydrocarbons, particularly those having various substituent groups, can react with nitrogen dioxide to produce a type of plant damage different from that usually associated with smog and produce all the other effects as well.

The hydrocarbon derivatives, particularly the aldehydes and ketones, and even some of the chlorinated hydrocarbons, can also react with nitrogen dioxide in the atmosphere to produce eye irritation, aerosols, and ozone. Further, some of the aldehydes and nitro derivatives are, themselves, lachrymators and some of the chlorinated hydrocarbons are rather toxic.

The hydrocarbons are further indicated because photochemical reactions in which they participate sometimes produce hydrocarbon derivatives such as aldehydes, ketones, and nitro-substituted organics, which in turn react to increase the production of smog effects.

3. Inorganic Gases

1.25 Inorganic gases include oxides of nitrogen, oxides of sulphur, carbon monoxide, and much smaller quantities of ammonia, hydrogen sulphide, and chlorine. The principal source of the oxides is the combustion of fuel for industrial, commercial and domestic uses; for transportation; for space heating; and for generation of power.

Oxides of Nitrogen

1.26 Nitrogen (N) is in itself a colourless, tasteless, odourless gas that constitutes 78 per cent of the atmosphere.

A number of oxides of nitrogen occur, but only nitric oxide and nitrogen dioxide are important as air contaminants.

The first, nitric oxide (NO), a colourless, somewhat toxic gas, is formed through the direct combination of nitrogen and oxygen from the air in the intense heat of any combustion process. Nitric oxide in the atmosphere is then able in the presence of sunlight to combine with additional oxygen to form nitrogen dioxide (NO_2). The oxidation of nitric oxide to nitrogen dioxide is very rapid at high concentrations in air, but is slow at low concentrations except in the presence of hydrocarbons and sunlight.

Since nitrogen dioxide is formed so readily by photochemical action, it is usually thought of as a product of the photochemical process. But actually it may be formed whenever nitric oxide is a by-product of sufficiently high burning temperatures, with or without photochemical action. It is also a product or by-product of a number of industries, including fertilizer and explosives manufacturing.

Thermo-generating plants which operate at high temperatures can also be a serious source of oxides of nitrogen. In these plants the amount produced increase to staggering figures as temperatures exceed $1,650^{\circ}\text{C}$. For example, in going from 540° to $1,650^{\circ}\text{C}$, the nitric oxide concentration increases 1800 times, and in going from 540° to $2,200^{\circ}\text{C}$, it increases 13,000 times.

Nitrogen dioxide is the only important and widespread pollutant gas that is coloured (yellow-brown). As a result, it can significantly affect

visibility. It has a pungent, sweetish odour detectable at 1 to 3 parts per million, fortunately a level seldom reached in polluted atmospheres.

Nitric oxide is considerably less toxic than nitrogen dioxide. It acts as an asphyxiant when in concentrations great enough to reduce the normal oxygen supply from the air. Nitrogen dioxide, on the other hand, in concentrations of approximately 5 ppm, can produce lung injury and oedema, and in greater concentrations, fatal lung damage. It is an insidious gas as fatal amounts may be breathed without significant discomfort, although high concentrations may produce moderate irritation and coughing at time of exposure.

Nitrogen dioxide reacts with raindrops or water vapour in the air to produce nitric acid (HNO_3), which, even in small concentrations, can corrode metal surfaces in the immediate vicinity of the source. Vegetation, too, can be injured when it grows close to factories handling large amounts of nitric acid. The nitrogen oxides present in the ordinary community's air, however, are probably always too low to damage plant life.

The dioxide, then, is heavily indicated as an undesirable constituent of the atmosphere, regardless of the type of air pollution problem under consideration. Nitric oxide is indicated too, because of its ability to produce the dioxide by atmospheric oxidation. Fortunately, no link between atmospheric concentrations of nitrogen oxides and actual injury or illness in humans or animals has been reported yet.

Oxides of Sulphur

1.27 Air contaminants classified as oxides of sulphur consist essentially of only two compounds, sulphur dioxide (SO_2) and sulphur trioxide (SO_3). The primary source of both is the combination of atmospheric oxygen with the sulphur in certain fuels during their combustion. The total emitted quantities of the substances are, therefore, directly related to the sulphur content and total quantities of the principal fuels used in a community.

The major oxide of sulphur that is produced in combustion is sulphur dioxide (SO_2), a heavy, pungent, colourless gas that dissolves easily in water vapour to form a solution of sulphurous acid (H_2SO_3). Sulphurous acid, mildly corrosive, is used as a bleaching agent in industry. It joins slowly with the oxygen in the air (or quickly if catalysts are present) to become the even more corrosive, irritating mist, sulphuric acid (H_2SO_4).

Sulphuric acid can also be formed by a different route. Sulphur dioxide can be oxidized directly (changed chemically by combining with oxygen) to sulphur trioxide (SO_3), which can be either a colourless liquid or a white solid aerosol. Sulphur trioxide is a likely product when combustion takes place with excess oxygen. The change is abetted by the catalytic action of some of the ash residue, especially the iron oxides that form on boiler tubes and walls. As sulphur dioxide leaves the smoke stack it usually diffuses rapidly, so that oxidation to sulphur trioxide takes place rather slowly. But, with time, sulphur trioxide can build up substantially and react very quickly with water vapour to form sulphuric acid.

Primarily, gaseous oxides of sulphur in the atmosphere are significant because of their toxicity. Both the sulphur dioxide and sulphur trioxide are capable of producing illness and lung injury even at small concentrations, from 5 to 10 ppm.

Sulphur dioxide by itself also produces a characteristic type of damage to vegetation whereby portions of the plant leaves are bleached in a specific pattern. In concentrations as small as 5 ppm, sulphur dioxide is irritating to the eyes and respiratory system. It is colourless, with a characteristic pungent suffocating odour, and high concentrations can produce oedema, respiratory paralysis, and death, but become intolerable before reaching immediately dangerous levels.

Both the dioxide and trioxide can combine with particles of soot and other aerosols to produce contaminants more toxic than either alone. The combination of the dioxide and the trioxide with their acid aerosols has also been found to exert a synergistic effect on their individual toxicities. These mixtures were apparently responsible for the illness and death associated with the famous air pollution incidents that occurred in the Meuse Valley, Belgium; in Donora, Pennsylvania; and, more recently, in London, England.

other Sulphur Compounds: Hydrogen Sulphide, Organic

Sulphides and Mercaptans

1.28 Both thermal and catalytic cracking processes in oil refining operations convert the sulphur contained in the crude oil into hydrogen sulphide (H_2S) in the gasoline fractions. The same substances are also produced in Kraft paper mill processes. When hydrogen

sulphide is released to the atmosphere as a gas, it manifests a characteristic rotten egg odour. Mercaptans also exhibit varying types of strong unpleasant odours such as garlic, decayed garbage, skunk or onions from relatively small gas concentrations. Hydrogen sulphide is detectable at 0.12 ppm and mercaptans from 0.001 to 0.041 ppm. H₂S will also discolour some painted surfaces with lead pigments under humid conditions.

Carbon Monoxide

1.29 Carbon monoxide (CO) results from the incomplete combustion of any carbonaceous fuel. Automobiles provide a principal source as it comprises from 1% to 5%, or more, of the total emission, depending on carburettor adjustment. Automobile fumes constitute about 97% of the total carbon monoxide emitted in a large metropolitan area and this is the only important source of this pollutant at ground level.

It is a colourless gas which has been described as odourless to practically odourless. It is non-irritating but causes dizziness, headache, weakness, heart palpitation, staggering, confusion, nausea, vomiting, unconsciousness, convulsion, weak pulse, slow respiration, and death. It produces its damage by combining with haemoglobin of the blood, so excluding oxygen from the tissues, leading to asphyxiation of the cells, especially nerve cells. Concentrations of 200 ppm and greater are required to produce illness and death. It has been detected in the atmosphere of various urban centres of the world at concentrations from 10 to 150 ppm. Greater concentrations have occasionally been measured in confined spaces such as tunnels and large, poorly ventilated garages. Atmospheric concentrations have not yet linked

to fatalities, but have sometimes been implicated in short-term illnesses of traffic officers.

Miscellaneous Inorganic Gases

1.30 These include ammonia, hydrogen sulphide, chlorine, and fluorine or fluorides. They are normally only detected in trace quantities in the atmosphere but all are toxic in small to moderate concentrations, and the first three have unpleasant odours. Hydrogen sulphide can cause discolouration of certain kinds of paint; ammonia can discolour certain fabric dyes and is corrosive to copper, brass, aluminum and zinc; chloride can discolour certain fabric dyes; fluorine and fluorides, especially hydrogen fluoride, are highly toxic, corrosive, and capable of causing damage to vegetation, and illness and injury to humans and animals.

Many other inorganic gases may be individually or locally objectionable or toxic. These are of relatively minor importance and will not be discussed here.

SUBJECT:

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

TOPIC: 2

EFFECTS OF AIR POLLUTION

OBJECTIVES:

The trainee will be able to:

1. List and describe the four ways in which air pollution effects become apparent:
 - i) Reduction in visibility
 - ii) Damage to vegetation
 - iii) Soiling and property damage
 - iv) Physiological reaction

EFFECTS OF AIR POLLUTION

2.1 As the concentrations of contaminants in the atmosphere increase certain typical air pollution effects become apparent. These are:

1. Reduction in visibility
2. Damage to vegetation
3. Soiling and property damage
4. Physiological reaction

1. Reduction in Visibility

2.2 Visibility reduction is due to the concentration of aerosols in the atmosphere and indicates an air pollution condition in the same manner that the clouding or darkening of a liquid may be said to indicate pollution by impurities. Two types of air pollution occur which affect visibility:

- (a) Sky darkening
- (b) Haziness or light scattering

In the former the sky darkens and visibility is reduced by the physical obstruction of the sky illumination, as a result of clouds of contaminants and plumes of smoke and fumes from sources of pollution. In the latter a haze evolves from atmospheric reactions which alters sky illumination by scattering the light. The blue colour of the sky, it should be noted, is the result of the mass uniform scattering of light from the molecules of atmospheric gases. Similarly the colour of the sky is altered by pollution hazes depending on the size of the aerosols relative to the wave length of light. Aerosols of a size between 0.4 and 0.9 micron are most effective in light scattering.

The nuisance value of visibility reduction appears to be relative to the climate, geography, population density and heights of structures, and the viewing point of the average observer. In the Los Angeles area the maximum visibility possible from the sea to the mountains is sometimes of the magnitude of thirty-five miles. During a smog attack this visibility is reduced to less than five miles.

Visibility reduction is an indication of pollution accumulation and its measurement is one of the means by which pollution intensity is determined. Visibility records can be used to show daily, weekly, monthly and yearly variations, and reflect the changes which take place in weather, the industrial economy and the effects of control practices.

When the sky is darkened by air pollution it must also be remembered that the amount of available sunlight reaching the ground is being considerably reduced, and sunlight is essential to human and plant life.

2. Damage to Vegetation

2.3 Injury and disease to sensitive forms of life such as crops and plants resulting from air pollution have been clearly established. Injury can range from reduced growth and yield to complete plant destruction. The effect air pollution has in reducing available sunlight for vegetation is harmful in itself, but certain air contaminants are capable of causing bleaching, discolouration, stippling, stunting of growth, lesions, cell damage, spotting, pitting, drooping, defoliation, etc. Some forms of vegetation respond uniquely to

concentrations of certain contaminants, a fact which has the following implications for the study of air pollution:

- (a) Damage to any form of life serves to warn man of the presence of toxicants which may also adversely affect human health, cause crops grown for human consumption to become unmarketable or inedible, as well as poison foraging cattle.
- (b) Damage to plants may indicate the chemical reactivity of the air.
- (c) Economic damage sustained by commercial growers of plants and crops in polluted areas may point to the need for research and control to remove the suspected contaminants from the air, or the undesirability of growing sensitive crops.

The main airborne pollutants that injure plants are sulphur dioxide, fluorides, and oxidants. On occasion, chlorine, ammonia, ethylene, and particulate matter have caused injury. Any pollutant which injures vegetation is a phytotoxicant.

Toxic gases enter leaves via stomata (microscopic openings in the leaves where normal exchange of the gases oxygen and carbon dioxide occur). Inside the leaf the pollutant interferes with the metabolism of the cells causing leaf injury.

The injury may become visible in a short time and take the form of necrotic lesions (dead tissue) on the margins, or between the veins of the leaves. In the necrotic areas the cells are killed and the tissue collapses and dries to an ivory or reddish-brown colour.

The injury may develop slowly and become manifest as a yellowing, or chlorosis, of the leaf. The chlorotic tissues do not collapse but gradually lose their green colour.

The physiological processes of the plant may become upset, and there may be a reduction in the growth of various portions of the plant. Repeated injuries may result in the death of the plant.

The symptoms of injury caused by air toxicants are very similar to those of injuries caused by disease, insects, adverse weather, poor nutrition or mismanagement, and require diagnosis by specialists.

Examples of types of damage observed are as follows:

- (i) Silvering and bronzing of the undersides of many broad-leaved plants, particularly annuals, as a result of the presence of unsaturated hydrocarbons
- (ii) Retardation of growth of many plants, as a result of the presence of plant toxicants
- (iii) Stippling on grapes and tobacco, and bleaching on the upper surfaces of older leaves of some plants as a result of ozone
- (iv) Bleached areas between veins of some plants as a result of sulphur dioxide, which is capable of damaging plants at relatively low concentrations
- (v) Other forms of damage to plants include accumulative poisoning from fluorine and lead compounds, damage to leafy vegetables and flowers from sulphuric acid aerosols, etc.

3. Soiling and Property Damage

2.4 One of the first material effects of air pollution is the soiling of clothing, buildings and properties. A familiar annoyance is the soiling of clothing and textile materials exposed to air containing smoke, soot and dust. Air pollution has a direct influence on the cost of cleaning and laundering, on the marketability of merchandise, and the cleaning of buildings.

Air pollution may also damage property. The damage is usually of a cumulative nature, tends to shorten the durability of materials exposed to the atmosphere, and is generally caused by the inter-action of the contaminants with the surface or the protective coatings of materials in the form of:

corrosion (chemical or electro-chemical reaction)

erosion (mechanical abrasion of surfaces by wind-blown materials)

oxidation (such as rubber cracking from ozone and other oxidants present in the atmosphere)

spotting (contamination of surfaces by paints and oil droplets, carbon spheres and fly-ash)

Everyone has seen some example of this type of damage, maybe metal corrosion, damage to stone and masonry, or excessive cracking on rubber tyres, damage to automobile paint work, etc. The economic impact is quite significant.

Steam and sand-blast cleaning of exteriors of large buildings is a maintenance expense which increases as air pollution increases. Frequent cleaning of clothing and repainting of residences are other examples of the numerous items to consider in estimating economic loss from air pollution.

4. Physiological Reaction

2.5 Some years ago the United States' Surgeon-General stated, "There is no longer any doubt that air pollution is a hazard to health."

The United States' National Air Pollution Control Administration, in its publication No. AP-49, 1969, states: "Analyses of numerous epidemiological studies clearly indicate an association between air pollution, as measured by particulate matter accompanied by sulphur dioxide, and health effects of varying severity. This association is most firm for the short-term air pollution episodes."

The effects of air pollution on health vary with the age and physical condition of each individual, the nature and degree of concentration of the pollutant or pollutants, and the duration of exposure. The very young, the aged, and those with throat or lung sensitivity are specially susceptible. The incidence of bronchial and respiratory ailments is invariably high in large cities and prolonged exposure to even moderate concentrations of pollutants is deemed by medical authorities to be an important factor. Serious pollution episodes in which severe illnesses have been blamed on air contaminants have occurred in the Meuse Valley in Belgium, in Denora, Pennsylvania, and on a number of occasions in New York City, and in London, England.

Denora, an industrial community in a deep valley thirty miles south of Pittsburgh, provided a dramatic instance of a number of air pollution incidents in the United States.

There, during a five day calm in October 1948, air pollutants from mills, smelters and acid plants accumulated and thousands of illnesses were blamed on the occurrence, with several hundred hospitalized and twenty deaths. Over one hundred and thirty separate law suits were filed and, as a result of ensuing public outcry, in 1950 a comprehensive technical conference on air pollution was convened in Washington at the highest official level.

Denora's problem occurred during a temperature inversion with no air movement to dilute and disperse the pollutants. Similar circumstances prevailed in London, England, in 1952, and over a period of days the concentration of air pollutants in that area increased alarmingly, as did the incidence of cases of death and illness from various respiratory diseases, during and after the episode.

It is known from the results of such air pollution disasters, and from the toxic potentials now found in the atmosphere in many cities, that concentration of air pollution can be reached in the atmosphere which may cause irritation of the eyes and the respiratory tract, headache, nausea, allergy, illness and even death, and that continuous daily exposure to polluted air may cause life-shortening diseases.

Much remains to be known about the long range effects of low concentrations, particularly their influence on such respiratory diseases as emphysema, asthma, and lung cancer. Although data is insufficient to prove such relationships, most informed authorities on the subject believe that they exist to some degree.

SUBJECT:

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

TOPIC: 3

FUELS

OBJECTIVES:

The trainee will be able to:

1. Define "fuel";
2. Explain why lower rank coals when burning generate more smoke than those of higher rank;
3. Briefly explain the importance of the purchaser knowing the analysis of a coal;
4. Explain the importance of knowing the viscosity of fuel oil;
5. Briefly describe the methods used for burning waste wood as a fuel;
6. Briefly state how "coal gas", "producer gas", and "blast furnace gas" are produced.

FUELS

3.1 A fuel by definition is any substance used for combustion.

Combustion is the combination of the combustibles in the fuel with the oxygen of the air. The combustibles are carbon and hydrogen plus some sulphur.

Carbon forms the largest percentage of any fuel and if completely burned carbon dioxide (CO_2) is formed. If combustion is incomplete, carbon monoxide (CO) is formed. This may be due to insufficient air being supplied for complete combustion. The complete combustion of hydrogen produces moisture (H_2O) and the complete combustion of sulphur produces sulphur dioxide (SO_2).

Coal as a Fuel

3.2 Coal can be divided into the following classifications:

- Anthracite
- Semi-Anthracite
- Semi-Bituminous
- Bituminous
- Sub-Bituminous
- Lignite

The higher the rank, the higher the fixed carbon content and the lower the volatile content.

Anthracite burns nearly smokeless with a short bluish flame.

' Bituminous coal burns with a long yellow and smoky flame.

Lignite - Very little lignite is burned in Ontario. It burns with a bright, slightly smoky yellow flame and may be more important as a fuel if the Onakawana Lignite field is developed.

Coal Analysis

3.3 Coal is purchased according to its analysis and the purchaser should be provided with an analysis representing the coal purchased. A typical analysis of an Anthracite coal could be:

Proximate Analysis:

Moisture	3.45%
Volatile matter	2.75%
Fixed Carbon	87.90%
Ash	5.90%

Ultimate Analysis:

Carbon	88.86%
Hydrogen	2.04%
Nitrogen	0.90%
Oxygen	1.95%
Sulphur	0.35%
Ash	5.90%

Heating Value by:

Calorimeter	13,950 Btu
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Classification:

Carbon Hydrogen ratio	42.50
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Grindability Index:

(Hargrove Index)

Size:

(can vary widely but size should be specified)

This information should conform with the purchasing specifications specified by the purchaser, the requirements of the coal burning equipment and also relate to the coal furnished by the supplier.

Coal may be handled many times between the time the analysis is made, probably at the mine, and delivery to the consumer. There is a possibility that the wrong coal may be delivered, that the proper coal may be mixed with another and that the size of the coal may be smaller than specified due to the coal fracturing during shipment.

Combustion zones of coal burning equipment are designed to burn specific types of coal. A coal with more hydrocarbon content will require a larger furnace area, for instance.

Combustion equipment is also designed to burn certain sizes of coal, for example:

5 inch lump is sold for hand firing equipment
5 X 2 inch egg is sold for domestic hand
firing and gas producers
2 X 1½ inch nut is sold for domestic, hand
firing and small industrial stokers
1½ X 3/4 inch stoker coal is used in small
industrial stokers and in domestic
stokers
2/4 X 0 slack is used for industrial stokers
and pulverizers

Stoker coal can be further classified but it is sufficient to say here that problems may be encountered if the size gradient of the coal is not specified for the equipment.

Each large user of the coal should check the coal delivered against the analysis supplied for the equipment.

The ultimate analysis can be done by a local testing company.

The proximate analysis can usually be done by the operating engineers.

The size can usually be checked by the operating engineers.

As well as the possibility of poor operation of stoking equipment and poor combustion, coal with too high a percentage of slack and fines may result in the overloading of the dust collection equipment and excessive fly-ash emissions from the stack.

3.4 Table 3-1 shows the collection efficiencies for common types of fly-ash control equipment.

Tables 3-2 and 3-3 illustrate the emissions to be expected from coal burning equipment.

TABLE 3-1 RANGE OF COLLECTION EFFICIENCIES FOR COMMON TYPES OF FLY-ASH CONTROL EQUIPMENT^a

Type of furnace	Range of collection efficiencies, %			
	Electrostatic precipitator	High-efficiency cyclone	Low-resistance cyclone	Settling chamber expanded chimney bases
Cyclone furnace	65 to 99.5 ^b	30 to 40	20 to 30	10 ^b
Pulverized unit	80 to 99.5 ^b	65 to 75	40 to 60	20 ^b
Spreader stoker	99.5 ^b	85 to 90	70 to 80	20 to 30
Other stokers	99.5 ^b	90 to 95	75 to 85	25 to 50

^aReferences 1 and 2.

^bThe maximum efficiency to be expected for this collection device applied to this type source.

Table 3-2 EMISSION FACTORS FOR BITUMINOUS COAL COMBUSTION WITHOUT CONTROL EQUIPMENT
EMISSION FACTOR RATING: A

Furnace size, 10^6 Btu/hr heat input ^a	Particulates ^b		Sulfur oxides ^c		Carbon monoxide		Hydro- carbons ^d		Nitrogen oxides		Aldehydes	
	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned
Greater than 100 ^e (Utility and large industrial boilers)												
Pulverized												
General	16A	8A	38S	19S	1	0.5	0.3	0.15	18	9	0.005	0.0025
Wet bottom	13A ^f	6.5A	38S	19S	1	0.5	0.3	0.15	30	15	0.005	0.0025
Dry bottom	17A	8.5A	38S	19S	1	0.5	0.3	0.15	18	9	0.005	0.0025
Cyclone	2A	1A	38S	19S	1	0.5	0.3	0.15	55	27.5	0.005	0.0025
10 to 100 ^g (large commercial and general industrial boilers) ^g												
Spreader stoker ^h	13A ⁱ	6.5A	38S	19S	2	1	1	0.5	15	7.5	0.005	0.0025
Less than 10 ^j (commercial and domestic furnaces)												
Spreader stoker	2A	1A	38S	19S	10	5	3	1.5	6	3	0.005	0.0025
Hand-fired units	20	10	38S	19S	90	45	20	10	3	1.5	0.005	0.0025

^a1 Btu/hr = 0.252 kcal/hr.

^bThe letter A on all units other than hand-fired equipment indicates that the weight percentage of ash in the coal should be multiplied by the value given.
Example: If the factor is 16 and the ash content is 10 percent, the particulate emissions before the control equipment would be 10 times 16, or 160 pounds of particulate per ton of coal (10 times 8, or 80 kg of particulates per MT of coal).

^cS equals the sulfur content (see footnote b above).

^dExpressed as methane.

^eReferences 1 and 3 through 7.

^fWithout fly-ash reinjection.

^gReferences 1, 4, and 7 through 9.

^hFor all other stokers use 5A for particulate emission factor.

ⁱWithout fly-ash reinjection. With fly-ash reinjection use 20. This value is not an emission factor but represents loading reaching the control equipment.^j

^jReferences 7, 9, and 10.

Table 3-3 EMISSIONS FROM ANTHRACITE COAL COMBUSTION WITHOUT CONTROL EQUIPMENT
EMISSION FACTOR RATING: B

Type of furnace	Particulate ^{a,b}		Sulfur dioxide ^c		Sulfur trioxide ^{c,d}		Hydrocarbons ^{e,f}		Carbon monoxide ^g		Nitrogen oxides ^{d,h}	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Pulverized (dry bottom), no fly-ash reinjection	17A	8.5A	38S	19S	0.5S	0.25S	0.03	0.015	1	0.5	18	9
Overfeed stokers, no fly-ash reinjection ⁱ	2A	1A	38S	19S	0.5S	0.25S	0.2	0.1	(2 to 10) ^j	(1 to 5)	(6 to 15) ^k	(3 to 7.5)
Hand-fired units	10	5	36S	18S	0.8S	0.4S	2.5	1.25	90	45	3	1.5

^aReferences 2 through 7.

^bA is the ash content expressed as weight percent.

^cS is the sulfur content expressed as weight percent.

^dReferences 5, 7, and 8.

^eBased on Reference 2 and bituminous coal combustion.

^fExpressed as methane.

^gBased on bituminous coal combustion.

^hEmitted as NO, but calculated as NO₂.

ⁱBased on data obtained from traveling-grate stokers in the 12 to 180 Btu/hr (3 to 45 kcal/hr) heat input range. Anthracite is not burned in spreader stokers.

^jUse high side of range for smaller-sized units [less than 10×10^6 Btu/hr (2.5×10^6 kcal/hr) heat input].

^kUse low side of range for smaller-sized units [less than 10×10^6 Btu/hr (2.5×10^6 kcal/hr) heat input].

NOTE: Approximate efficiencies of control devices used for anthracite are: cyclone, 75 to 85 percent, and electrostatic precipitator, 85 percent.

3.5 The following is a summary of the effects of the primary characteristics of coal on the various parts of a large utility boiler:

Volatile matter

1. Affects volume of primary air required, degree of air preheating
2. Dictates location and design of burners

Ash content

1. Reduces burning capacity of furnace
2. Retards combustion, increases carbon loss
3. Affects precipitator design and handling costs

Sulphur

1. Affects slagging characteristics
2. Limits minimum gas exit temperature from air heater

Moisture

1. Reduces handling and burning capacity
2. Reduces combustion efficiency
3. Affects burning characteristics - increases flame length
4. Requires more drying in pulverizer

Ash-fusion temperature

1. Influences type of furnace bottom discharge
2. Affects slagging characteristics

Coal size and grindability

1. Affects mill capacity and grinding costs
2. Size affects efficiency of stoker or cyclone burners

Oil as a Fuel

3.6 Liquid fuels are derivatives consisting of mixtures of hydrocarbon compounds. Since a chemical analysis of the compounds which comprise the mixture is very difficult, it is common practice to make an analysis of several physical measurements instead.

Most fuel oils contain 83 to 88% carbon and 6 to 12% hydrogen. Since all fuel oils are so similar in chemical analysis and since the physical properties have a far greater effect on the operation of the fuel burning equipment, these physical properties are more commonly measured and specified by the oil companies.

The most significant are as follows:

Specific Gravity

3.7 The specific gravity of most petroleum fuels is less than 1 (lighter than water) and is expressed as a decimal, approximately 0.85 for distillate fuels and 0.975 for residual fuels.

Generally speaking, gravity is related to the quality of the oil in the following manner; as the gravity decreases,

1. the viscosity decreases
2. the carbon residue decreases
3. the heat content per pound increases but the heat content per gallon decreases
4. the carbon content decreases and the hydrogen content increases

Viscosity

3.8 The viscosity of a liquid is a measure of its internal friction.

If a liquid flows freely, it is said to have a low viscosity.

Viscosity is usually expressed as:

SUS Saybolt Universal Seconds at 100°F or 210°F
for lighter grades of fuel oil

SFS Saybolt Furol Seconds at 770°F or 122°F
for heavy fuel oils

SFS X 10 = approx. SUS equivalent

The viscosity of the fuel will determine whether or not heat must be applied to the fuel before combustion and also the type of fuel burning equipment used to burn the fuel.

Burner manufacturers specify the grade of fuel oil for which their burners are designed, the pre-heat temperature of the oil if required and also the pressure at which the oil should be pumped into the burner.

Bottom Sediment and Water (BS&W)

3.9 Bottom sediment and water may become important if the operator finds that his fuel oil strainers are clogging up. Water in small quantities will be noted as small sparks in the flame. Water may be picked up due to condensation but usually only gives problems if introduced to the oil in larger quantities from a leak in the oil heating equipment.

Sulphur

3.10 Sulphur is present in many petroleum products because crude oil itself contains this material in a variety of forms of which the most common are, free sulphur, hydrogen sulphide, mercaptans, disulphides and other

complex compounds.

Distillate fuels usually contain from 0.1% to 1.0% sulphur by weight and residual fuels, in most of Canada, contain up to 3.0% sulphur by weight in type 6 fuel. Combustion of sulphur in fuels contributes to air pollution as sulphur dioxide (SO_2) and sulphur trioxide (SO_3). Regulation 17 made under the Environmental Protection Act limits the sulphur content of fuel oils burnt in Metropolitan Toronto as of January 1st, 1974 to 0.5% in No. 1 and 2 fuel oils, to 1.5% in No. 3, 4, 5 and 6 fuel oils and to 1.5% in coal.

3.11 Table 3-4 opposite illustrates the emissions to be expected from oil burning equipment. Particulate matter in this case will be in the form of unburned carbon with no fly-ash present.

Table 3-4 EMISSION FACTORS FOR FUEL OIL COMBUSTION
EMISSION FACTOR RATING: A

Pollutant	Type of unit							
	Industrial and commercial				Domestic			
	Power plant		Residual		Distillate			
Pollutant	lb/10 ³ gal	kg/10 ³ liters	lb/10 ³ gal	kg/10 ³ liters	lb/10 ³ gal	kg/10 ³ liters	lb/10 ³ gal	kg/10 ³ liters
Particulate ^a	8	1	23	2.75	15	1.8	10	1.2
Sulfur dioxide ^{b,c}	157S	19S	157S	19S	142S	17S	142S	17S
Sulfur trioxide ^{b,c}	2S	0.25S	2S	0.25S	2S	0.25S	2S	0.25S
Carbon monoxide ^d	3	0.4	4	0.5	4	0.5	5	0.6
Hydrocarbons ^e	2	0.25	3	0.35	3	0.35	3	0.35
Nitrogen oxides (NO ₂) ^f	105 ^g	12.6 ^g	(40 to 80) ^h	(4.8 to 9.6) ^h	(40 to 80) ^h	(4.8 to 9.6) ^h	12	1.5
Aldehydes (HCHO) ⁱ	1	0.12	1	0.12	2	0.25	2	0.25

^aReferences 2 through 6.^bReference 2.^cS equals percent by weight of sulfur in the oil.^dReferences 2, 7 through 10, 12, and 15.^eReferences 2, 6, and 9 through 12.^fReferences 2 through 6, 9, 10, 12, 13, 15, and 16.^gUse 50(6) for tangentially fired units.^hUse 40 (4.8) for tangentially fired units and 80 (9.6) for horizontally fired units.ⁱReferences 2, 9, 11, and 14.

Analysis (% by vol)		Propane Gas	Methane Gas		Ethylene Gas		Carbon Monoxide		Carbon Dioxide		Nitrogen		Oxygen		Benzene	
			%	%	%	%	%	%	%	%	%	%	%	%	%	%
Hydrogen	H ₂	14.0	34.0	36.8	53.0	57.4	47.9	42.16	52.61							
Methane	CH ₄	3.0	15.5	24.9	31.6	28.5	33.9	37.14	27.94							
Ethylene	C ₂ H ₄	—	4.7	3.7	2.7	2.9	5.2	4.76								
Carbon Monoxide	CO	27.0	32.0	17.4	6.3	5.1	6.1	11.93	5.95							
Carbon Dioxide	CO ₂	4.5	4.3	3.4	1.8	1.4	2.6	3.13	1.49							
Nitrogen	N	50.9	6.5	12.0	3.4	4.2	3.7									
Oxygen	O	0.6	0.7	0.3	0.2	0.5	0.6									
Benzene	C ₆ H ₆	—	2.3	1.5	1.0										0.88	
	Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
Specific Gravity (air = 1.0)		0.86	0.67	0.58	0.39	0.35	0.42	0.47	0.40							
Higher Heating Value (Btu, ft ³)		163	534	545	581	528	590	647	465							
Fuel (lb/10,000 Btu)		4.06	0.951	0.814	0.511	0.497	0.536	0.554	0.639							
Theoretical Air (lb/10,000 Btu)		5.80	6.49	6.64	6.72	6.69	6.79	6.90	6.69							
Total Moisture (lb/10,000 Btu)		0.583	0.725	0.859	1.005	1.086	1.014	0.946	1.110							

* Gross at 60°F and 30 in. Hg.

TABLE 3-5 Analyses of Various Manufactured Gases

Type	Analysis	Percent by Volume			Combustion Data	Saturated Gas at 60°F	Gas of 100% with 30% H ₂ O
		Dry	Saturated at 60°F	Above 100°F 30% H ₂ O			
Lean	CO	14.9	14.40	13.69	Theoretical Air (lb/10,000 Btu) H ₂ O (vapor) from Fuel (lb/10,000 Btu) H ₂ O from H ₂ and CH ₄ in Fuel (lb/10,000 Btu) H ₂ O (total) from Fuel (lb/10,000 Btu) Wet Gas from Fuel (lb/10,000 Btu) Density (lb/cu ft at 60°F and 30 in. Hg)	5.6850	5.5850
	CO	24.1	23.27	22.13		0.1937	0.4840
	H ₂	2.5	2.42	2.29		0.1482	0.1444
	CH ₄	0.1	0.10	0.09		0.3419	0.6284
	N	58.4	56.40	53.55		9.2900	9.4100
	H ₂ O	0.0	3.41	8.25		0.0778	0.0763
	Btu/cu ft	100.0	100.00	100.00			
Medium	CO	13.3	12.87	12.22	Theoretical Air (lb/10,000 Btu) H ₂ O (vapor) from Fuel (lb/10,000 Btu) H ₂ O from H ₂ and CH ₄ in Fuel (lb/10,000 Btu) H ₂ O (total) from Fuel (lb/10,000 Btu) Wet Gas from Fuel (lb/10,000 Btu) Density (lb/cu ft at 60°F and 30 in. Hg)	5.6800	5.5900
	CO	25.7	24.80	23.60		0.1826	0.4574
	H ₂	2.5	2.42	2.29		0.1398	0.1365
	CH ₄	0.1	0.10	0.09		0.3224	0.5942
	N	58.4	56.40	53.55		8.6800	8.8200
	H ₂ O	0.0	3.41	8.25		0.0771	0.0757
	Btu/cu ft	100.0	100.00	100.00			
Rich	CO	11.5	11.11	10.57	Theoretical Air (lb/10,000 Btu) H ₂ O (vapor) from Fuel (lb/10,000 Btu) H ₂ O from H ₂ and CH ₄ in Fuel (lb/10,000 Btu) H ₂ O (total) from Fuel (lb/10,000 Btu) Wet Gas from Fuel (lb/10,000 Btu) Density (lb/cu ft at 60°F and 30 in. Hg)	5.6900	5.5950
	CO	22.5	26.56	25.25		0.1721	0.4310
	H ₂	2.5	2.42	2.29		0.1317	0.1285
	CH ₄	0.1	0.10	0.09		0.3038	0.5595
	N	58.4	56.40	53.55		8.1100	8.2300
	H ₂ O	0.0	3.41	8.25		0.0764	0.0750
	Btu/cu ft	100.0	100.00	100.00			
Coke Rates and Gas Thermal Values at Typical Blast Furnaces							
Lb Coke/Net Ton of Pig				Average Gas Btu/Cu Ft of Dry Gas			
1600 to 1700				87 Lean			
1701 to 2000				92 Medium			
above 2000				98 Rich			

(Courtesy Iron & Steel Engineer)

TABLE 3-6 Analyses of Typical Blast Furnace Gases

Gas As A Fuel

3.12 Gas as a fuel probably creates fewer problems for the environmentalist than other forms of fuel. Natural gas has been treated to remove sulphur and the combustion of natural gas produces little particulate matter and small amounts of carbon monoxide (CO). The combustion of Butane or Propane produces even fewer objectionable products than does natural gas. Sulphurous compounds have been removed in the gas field before transmission to the consumer.

Other Gaseous Fuels

3.13 Some industries produce by-product gases. For the most part, the industries themselves burn their by-product gases to produce the heat needed in other parts of the process. Typical analyses are shown in Tables 3-5 and 3-6.

Briefly, the gases are:

Coal Gas - Coal gas is produced in a high temperature retort resulting in a destructive distillation of bituminous coal.

Producer Gas - Producer gas is produced by passing insufficient air or air and steam for complete combustion through an incandescent fuel bed of coal or coke in specially built gas producers.

Blast Furnace Gas - This is the gas discharge from the blast furnace during the smelting of iron ore.

3.14 The following tables (Tables 3-7 and 3-8) illustrate the emissions to be expected from the burning of natural gas, propane and butane.

Table 3-7 EMISSION FACTORS FOR NATURAL-GAS COMBUSTION
EMISSION FACTOR RATING: B

Pollutant	Type of Unit					
	Power plant		Industrial process boiler		Domestic and commercial heating	
	lb/10 ⁶ ft ³	kg/10 ⁶ m ³	lb/10 ⁶ ft ³	kg/10 ⁶ m ³	lb/10 ⁶ ft ³	kg/10 ⁶ m ³
Particulates ^a	15	240	18	290	19	302
Sulfur-oxides (SO ₂) ^b	0.6	9.6	0.6	9.6	0.6	9.6
Carbon monoxide ^c	17	270	17	270	20	320
Hydrocarbons ^d (CH ₄)	1	16 ^f	3	48	8	128
Nitrogen oxides (NO ₂) ^e	600	9600 ^f	(120 to 230) ^g	(1920 to 3700) ^g	(80 to 120) ^h	(1280 to 1920) ^h

^aReferences 3 and 4.

^bReference 5 (based on average sulfur content of natural gas of 2000 grains/10⁶ ft³ (4600 g/10⁶ m³)).

^cReferences 4 and 6 through 10.

^dReferences 4 and 6 through 11.

^eReferences 2 through 4 and 9 through 13.

^fUse 300 (4800) for tangentially fired units.

^gUse 120 (1920) for smaller industrial boilers <500 boiler horsepower and 230 (3700) for larger industrial boilers >7500 boiler horsepower.

^hUse 80 (1280) for domestic heating units and 120 (1920) for commercial units.

Table 3-8 EMISSION FACTORS FOR LPG COMBUSTION^a
EMISSION FACTOR RATING: C

Pollutant	Industrial process furnaces				Domestic and commercial furnaces			
	Butane		Propane		Butane		Propane	
	lb/10 ³ gal	kg/10 ³ liters	lb/10 ³ gal	kg/10 ³ liters	lb/10 ³ gal	kg/10 ³ liters	lb/10 ³ gal	kg/10 ³ liters
Particulates	1.8	0.22	1.7	0.20	1.9	0.23	1.8	0.22
Sulfur oxides ^b	0.09S	0.09S	0.01S	0.01S	0.09S	0.01S	0.09S	0.01S
Carbon monoxide	1.6	0.19	1.5	0.18	2.0	0.24	1.9	0.23
Hydrocarbons	0.3	0.036	0.3	0.036	0.8	0.096	0.7	0.084
Nitrogen oxides ^c	12.1	1.45	11.2	1.35	(8 to 12) ^d	(1.0 to 1.5) ^d	(7 to 11) ^d	(0.8 to 1.3) ^d

^aLPG emission factors calculated assuming emissions (excluding sulfur oxides) are the same, on a heat input basis, as for natural gas combustion.

^bS equals sulfur content expressed in grains per 100 ft³ gas vapor; e.g., if the sulfur content is 0.16 grain per 100 ft³ (0.366 g/100 m³) vapor, the SO₂ emission factor would be 0.09 x 0.16 or 0.014 lb SO₂ per 1000 gallons (0.01 x 0.366 or 0.0018 kg SO₂/10³ liters) butane burned.

^cExpressed as NO_x.

^dUse lower value for domestic units and higher value for commercial units.

Wood as a Fuel

3.15 Wood used for fuel is almost entirely a waste product from some type of wood using operation such as, lumber mills, pulp and paper mills and woodworking plants, some of which are located in built-up areas.

Wood waste is an inexpensive fuel but has the undesirable properties of widely varied moisture content, size and shapes. It may be dried in a kiln to approximately 11% moisture and range upwards to freshly cut wood of 50% moisture and, if river driven, even higher moistures could be expected. Particle size varies from sander dust to butt ends and large pieces of bark.

For the foregoing reasons, it is more difficult to burn wood waste without producing black smoke and odours. A large particle size gradient makes it difficult to pile burn without close attention to draught requirements.

Excess Air Requirements at Full Load

For pile burning as in dutch ovens	about 45%
For semi-pile burning as on inclined grates	30%
For spreader stoker firing	25%

Table 3-9 illustrates the emissions to be expected from wood burning equipment.

Methods of Conveying to Boiler House

3.16 Methods of conveying waste wood to the boiler house may be any, or a mixture, of the following:

Table 3-9 EMISSION FACTORS FOR WOOD
AND BARK COMBUSTION
IN BOILERS WITH NO
REINJECTION^{a,b}
EMISSION FACTOR RATING: C

Pollutant	Emissions	
	lb/ton	kg/MT
Particulates ^c	25 to 30	12.5 to 15.0
Sulfur oxides (SO ₂) ^d	0 to 3	0.0 to 1.5
Carbon monoxide	2	1
Hydrocarbons ^e	2	1
Nitrogen oxides (NO ₂)	10	5

^aReferences 1 through 4.

^bApproximately 50 percent moisture content.

^cThis number is the atmospheric emission factor without fly-ash reinjection. For boilers with reinjection, the particulate loadings reaching the control equipment are 30 to 35 lb/ton (15 to 17.5 kg/MT) fuel with 50 percent reinjection and 40 to 45 lb/ton (20 to 22.5 kg/MT) fuel with 100 percent reinjection.

^dUse 0 for most wood and higher values for bark.

^eExpressed as methane.

1. Pneumatic - such a system is usually feasible only for fairly large installations with long transporting distances, or where material must be picked up from a large number of separated points. Material may pass through the actuating fan or blower or may be introduced into the air stream down stream from the blower through rotary dischargers or valves. The pneumatic system is ideal for fine fuels such as sander dust and saw dust;
2. Drag chains - this method is very largely used since the wood fuel is not generally abrasive. Convenient methods can be employed to transfer from conveyor to conveyor, to separate and divide the fuel stream. Changes in elevation may be easily effected;
3. Belts - these are more subject to damage and are not as flexible as drag chain installations; and
4. Buckets - these may be employed for certain types of properly sized fuels to achieve elevation.

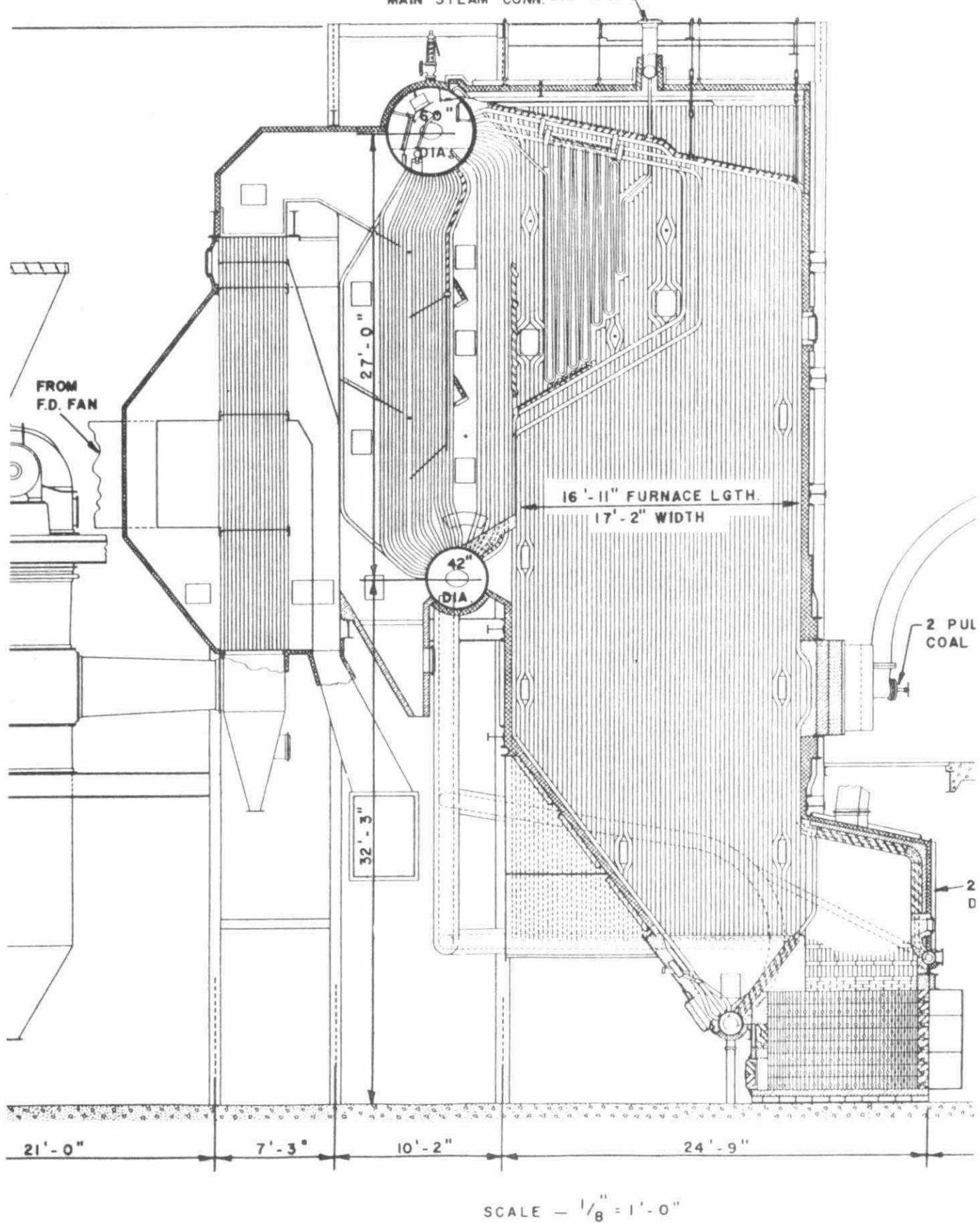
Methods of Burning

1. Pile Burning (Figure 3-1)
- 3.17 This method consists of dumping the fuel through a spout or a series of spouts into one or more cells or furnaces, where it remains in a conical pile and dries due to the heat of the furnace and is burned around the periphery and on the face of the cone. In general, while air is admitted through the grate, most of the air for combustion is admitted through layers or banks of tuyères located in the side walls. Such furnaces are usually largely refractory construction, including the tuyère areas. This is the oldest type of wood burning plant and it means that there is no direct

FIGURE 3-1

Typical pile-burning unit
for waste wood

MAIN STEAM CONN.



response between the rate of fuel input and the rate of steam output, such control having to be achieved by varying air flow.

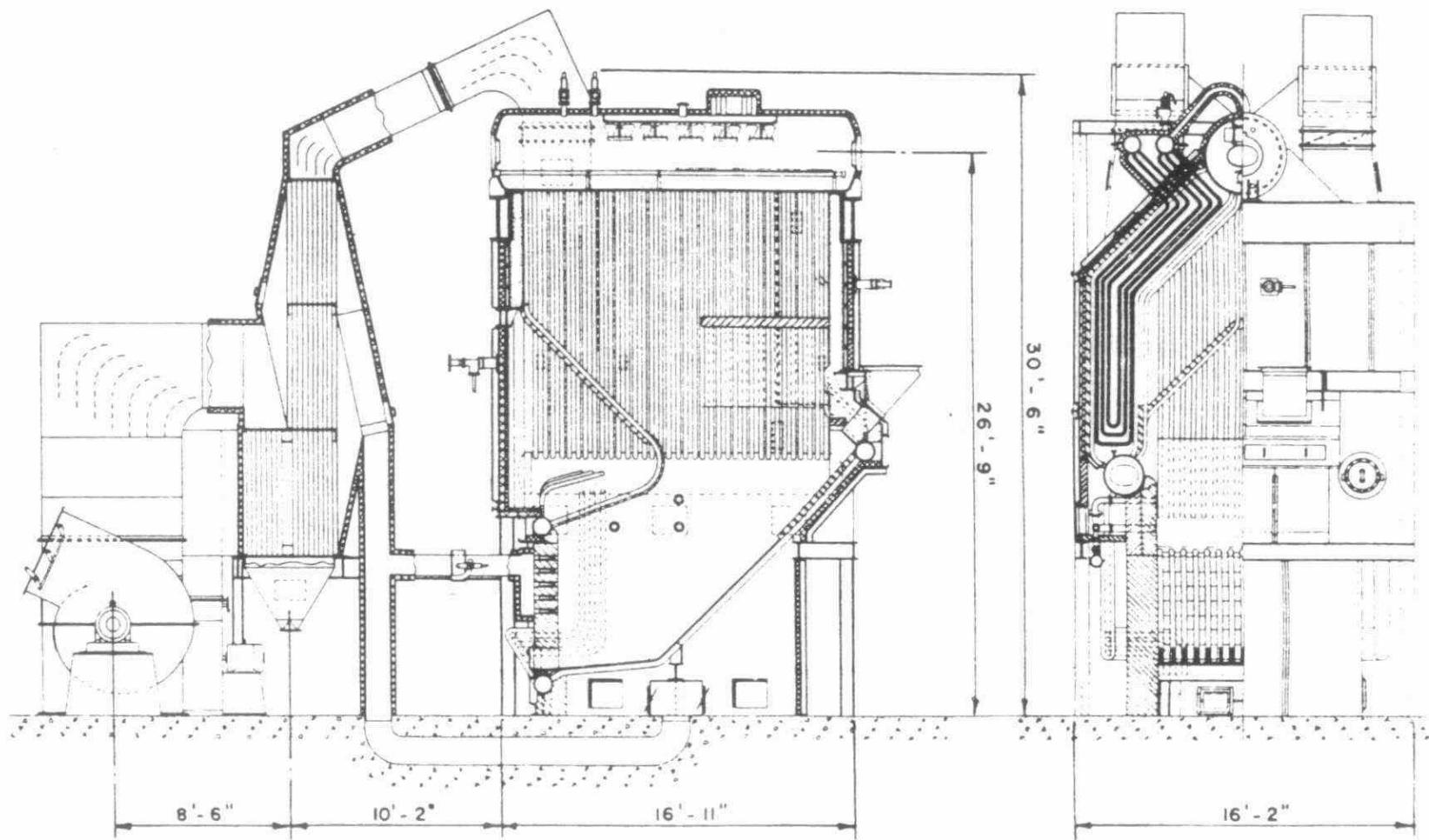
2. Inclined Grates (Figure 3-2)

3.18 Here the fuel enters in a ribbon, passes over the drying section where moisture is removed, then into the burning section where some increase in thickness of the fuel bed occurs, and then by gravity the ashes flow to the horizontal ash section at the bottom. This system of burning does not require accurate control of the incoming fuel. Steam output may be varied by changes in the air flow. Fuel size is not of significant importance and wet fuel can be adequately dried as it moves down the grate.

3. Spreader Stoker Firing (Figure 3-3)

3.19 Controlled feed rate to the stoker is essential. The fuel is delivered by the stoker into the furnace where some of it burns in suspension and the rest lands upon a grate of some type. Some installations are made with the stoker relatively high above the grate permitting more drying in the furnace before the material lands on the grate, and allows a larger percentage of the fuel to be burned in suspension. Such installations may allow a greater carry over of fly-ash. Other installations have the stoker set only high enough above the grate to achieve good distribution. Generally, care must be taken with this type of firing in regard to the amount of moisture in the fuel; with more than 55% moisture the addition of refractory or the use of supplementary fuel may be necessary.

There are two basic types of stokers employed. The older type is the mechanical stoker, which employs mechanical means of throwing the fuel into the furnace using paddles. This can only be used satisfactorily with suitably hogged and sized material, free from long, stringy pieces.



SCALE - $1/8'' = 1'-0''$

FIGURE 3-2

Inclined grate steam generator for burning wood waste

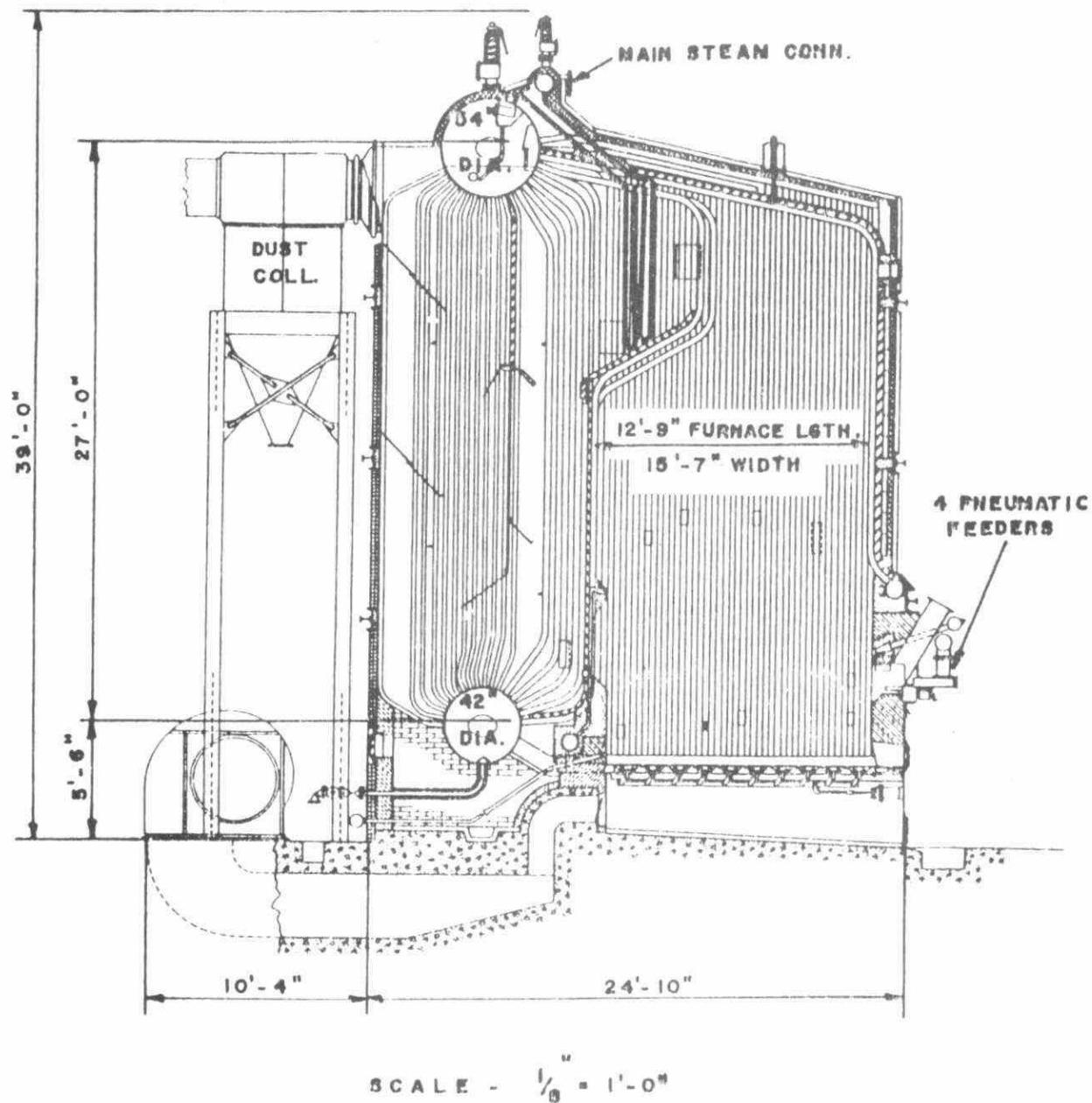


FIGURE 3-3

Steam generator equipped with pneumatic feeder (spreader stoker) for wood waste, and dumping grates.

The more recent application is the pneumatic type of stoker, where high pressure air is used to inject the fuel into the furnace. Little or no attention is required to fuel sizing with this type of equipment.

3.20 It should be noted that with stoker firing several different types of grates may be employed.

(a) The Stationary Grate (Figure 3-4)

3.21 An advanced and up-to-date design of this is the water cooled type (Fig.3-4a). This employs water cooling incorporated in the furnace circuit and a slight slope ensures adequate circulation in the tubes. Older installations employed non-water cooled stationary types of grates. While such grates have to be manually cleaned, simple grate castings have been developed which very effectively move the ash towards the ash pit door by means of steam jets.

(b) Dumping Grates (Figure 3-3)

3.22 These are invariably non-water cooled and the only difference is that the ashes may be dumped into the ash pit when necessary and operation continued immediately.

(c) Vibrating Grates

3.23 This is a means of bringing the ash to one end of the grate and may be of the water cooled or non-water cooled type.

(d) Travelling Grates (Figure 3-5)

3.24 A spreader stoker and continuous ash discharge type of grate. This installation shows provision for burning both wood and coal. Travelling grates permit a higher burning rate since temporary maldistribution of fuel on the grate is corrected as the grate moves along.

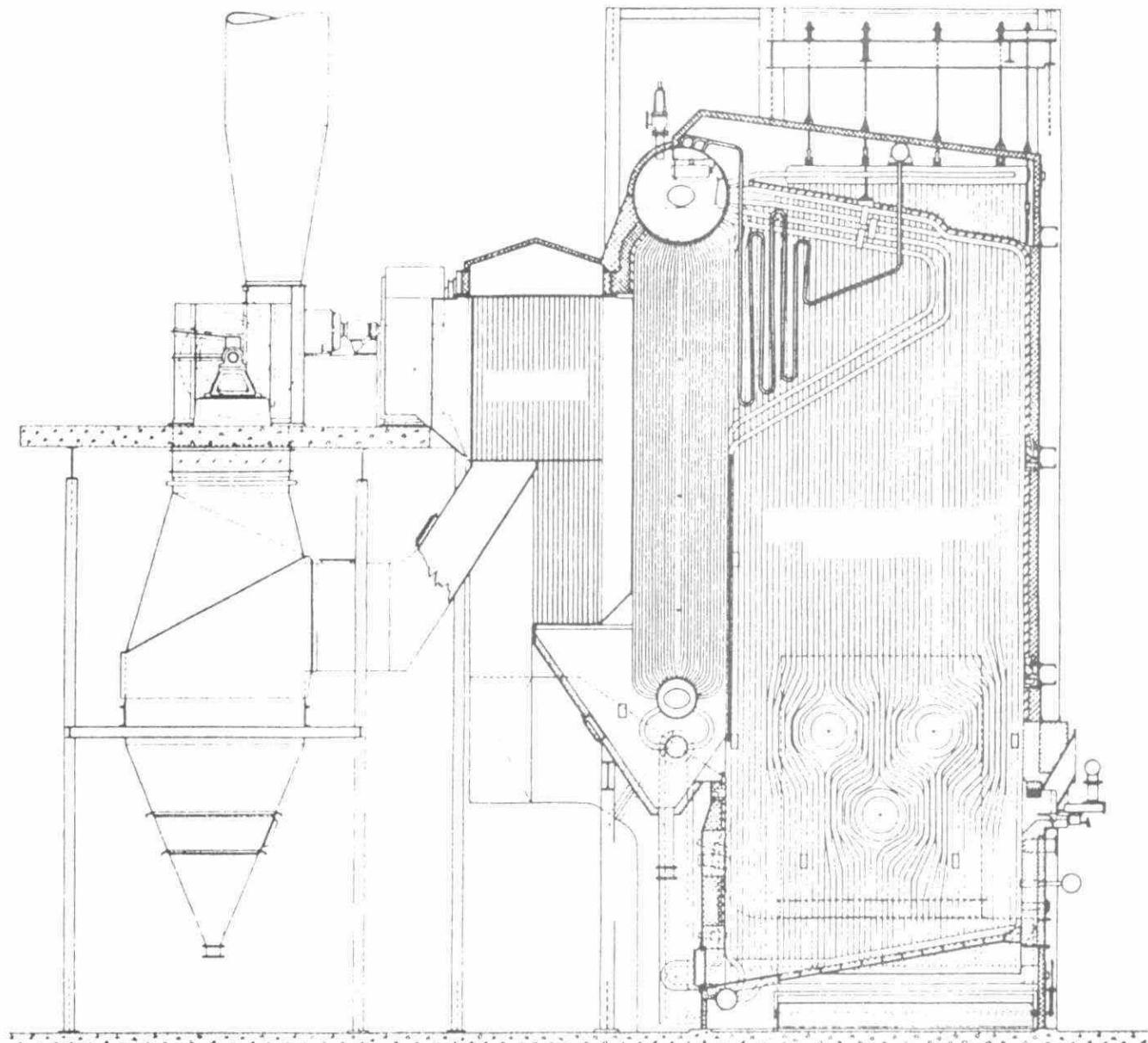


FIGURE 3-4

Water-cooled stationary grate installation

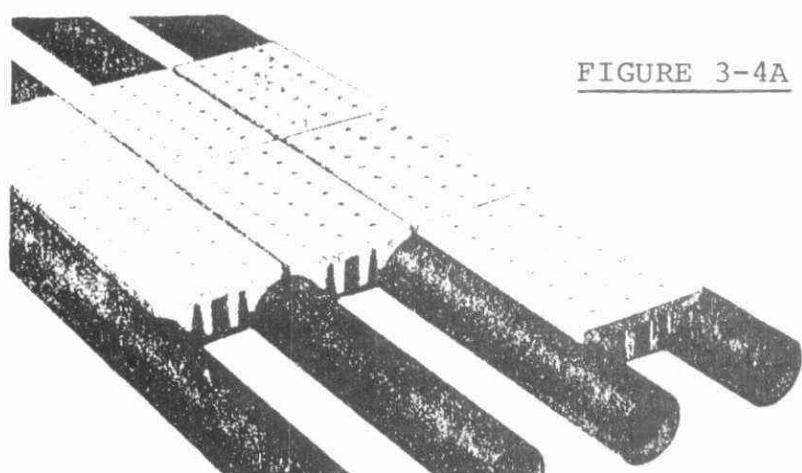


FIGURE 3-4A

Sections of Riley Water-cooled Grates

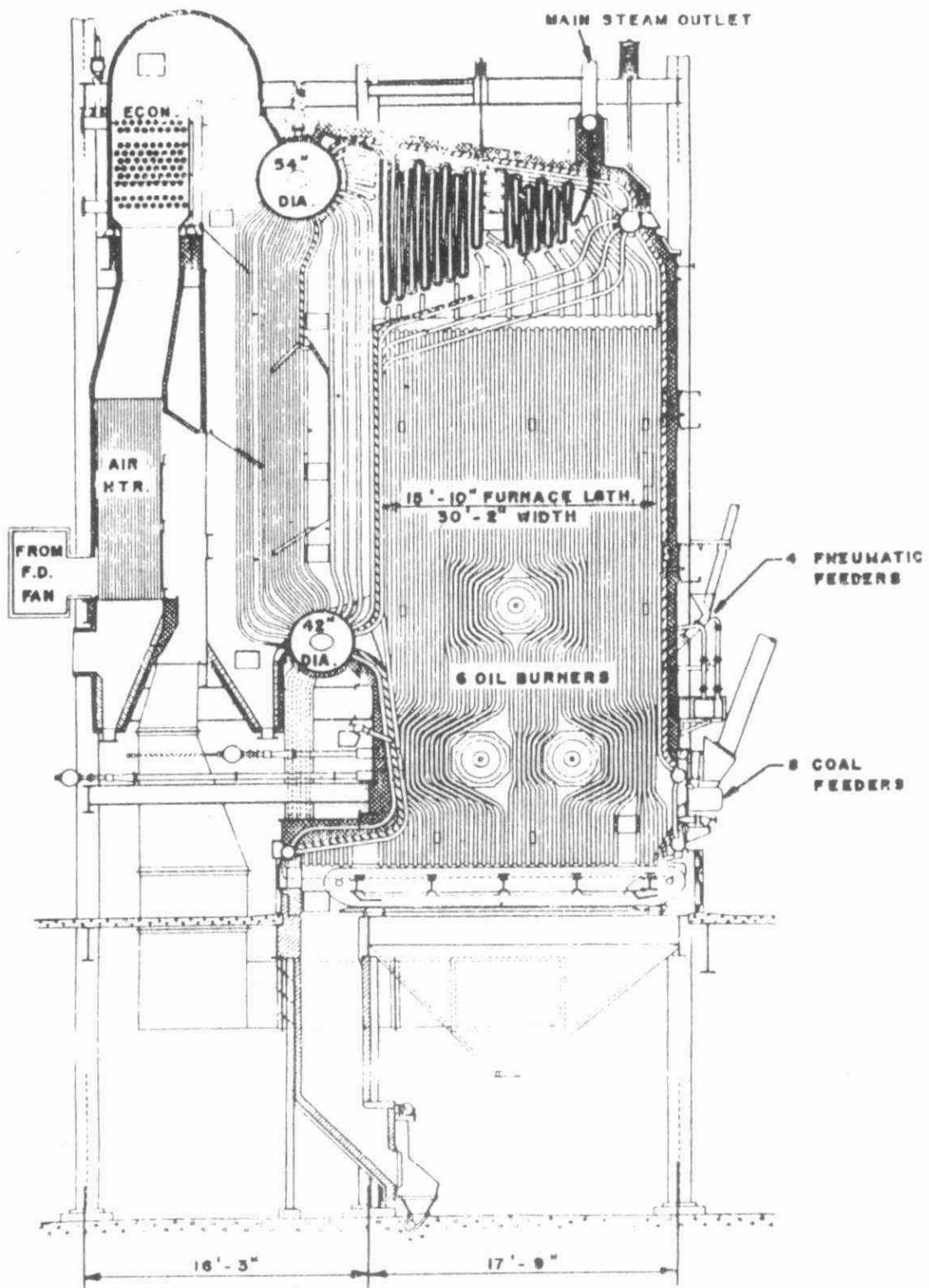


FIGURE 3-5

Installation with spreader stoker and travelling grate

3.25 With non-water cooled grates, where adequate consideration was not given to the fuels to be fired and the various conditions to ensure that the grate was always covered with fuel or ash, some very serious grate maintenance problems have occurred due to overheating. The water cooled grate does not have these limitations and is recommended wherever supplementary fuels are to be fired in suspension (oil, gas or pulverized coal).

4. Suspension Burning (Figure 3-3)

3.26 This is a modification of spreader stoker firing where fuel is introduced high in the furnace, suitable air admission and turbulence is achieved, and all or a large percentage of the fuel is burned in suspension with little or none falling upon the grate. Flyash carry over is more likely with this method. Special care must be taken to consider grate protection and some air must be allowed to come through the grate for this purpose.

SUBJECT:

TOPIC: 4

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

COMBUSTION

OBJECTIVES:

The trainee will be able to:

1. Define combustion;
2. Explain the significance of time, temperature, and turbulence as related to combustion;
3. Explain what is meant by:
 - (a) primary air
 - (b) secondary air
 - (c) excess air;
4. Explain what is meant by:
 - (a) natural draught
 - (b) induced draught
 - (c) forced draught
 - (d) balanced draught;
5. Answer the following questions:
 - (a) what is a flue gas analysis?
 - (b) what parts of the flue gas will it tell you about?
 - (c) what can it show about combustion efficiency?

COMBUSTION

Chemistry of Combustion

4.1 Combustion is a chemical reaction between fuels and oxygen in which considerable heat is generated. The oxygen is generally in the form of air.

The chemical elements of combustion are carbon, hydrogen, sulphur, oxygen and nitrogen. Of these carbon, hydrogen, and sulphur are combustibles. Nitrogen is an inert gas and is not combustible or a supporter of combustion. Oxygen is not combustible but supports the combustion of combustible materials.

Discounting nitrogen, which is inert, as we have seen, fuels consist essentially of carbon, hydrogen, sulphur and oxygen, either uncombined as elements or in combination as compounds. In combustion, the compounds and elements alike are burned to carbon dioxide and water vapour, and it is in this process that heat is developed.

Atomic Weight

4.2 The hydrogen atom is the lightest known and for comparative purposes it is given the value of 1. Since a carbon atom weighs twelve times as much its atomic weight is given as 12, and so on, as shown in the table below. Where an element is a gas its molecule contains 2 atoms, so that its molecular weight must be double that of its atomic weight.

4.3

Chemical Elements of Combustion

<u>Name</u>	<u>Symbol</u>	<u>Atomic Weight</u>	<u>Molecule</u>	<u>Molecular Weight</u>	<u>State</u>
Hydrogen	H	1	H ₂	2	Gas
Carbon	C	12			Solid
Nitrogen	N	14	N ₂	28	Gas
Oxygen	O	16	O ₂	32	Gas
Sulphur	S	32			Solid

4.4

Chemical Compounds of Combustion

All of the compounds of combustion are combinations of some two of the above five elements. Those of primary concern are as follows:

<u>Name</u>	<u>Symbol</u>	<u>Molecular Weight</u>	<u>State</u>	
Carbon Dioxide	CO ₂	44	Gas	Non-combustible
Carbon Monoxide	CO	28	Gas	Combustible
Sulphur Dioxide	SO ₂	64	Gas	Non-combustible
Water	H ₂ O	18	Liquid	Non-combustible

These four are the only true products of combustion, although in the flue gas they may be mixed up with many others.

4.5 Because oxygen and the fuel elements always combine in exact proportions, the results of combustion can be predicted, given an analysis of the fuel to be burned. Such calculations of combustion air requirements and products of combustion are theoretical, however, as they depend upon the combustible elements combining with the correct amount of oxygen in perfect circumstances.

In actual practice this happens rarely, as much depends on how the hydrocarbon gas and air mix, so analysis of flue gas from gas and oil-fired furnaces often reveals the presence of aldehydes, including formaldehyde.

To understand this we must look at the two ways in which hydrocarbons combine with oxygen in the combustion process.

4.6 In "hydroxylation" or "blue flame" burning, the hydrocarbon molecules associate with oxygen atoms to form hydroxylated compounds (alcohols or peroxides) that are unstable. These split up into aldehydes which, in turn, break down or oxidize until formaldehyde is produced. Depending on how much oxygen is present, formaldehyde may break down with heat to form carbon monoxide and hydrogen, or it may burn to water and carbon dioxide or carbon monoxide. Any carbon monoxide and hydrogen formed burns in the normal way.

So, it is clear that quite a few changes occur between the beginning and end of the burning operation, and that many intermediate products form and disappear. If combustion is incomplete, some of these compounds remain and show up in the flue gas. The faint acrid odour sometimes observed indicates the presence of one of these intermediate compounds, aldehydes.

4.7 In "thermal decomposition" or yellow-flame" burning, when hydrocarbons are subjected to high temperature they "crack" or break down chemically into other carbon and hydrogen combinations, and eventually into the basic elements, carbon and hydrogen, which may burn to carbon dioxide and water. This is what may happen to some of the gas near the edge of the flame where heat is intense. The cracking action sets free hydrogen, which burns in the flame,

and carbon particles which glow to incandescence and make the flame yellow. Normally the carbon particles burn out pretty well by the time they reach the flame edge, but if they remain suspended in the products of combustion we have smoke and soot.

We have looked at these two ways in which hydrocarbons burn as though they are separate processes, but, generally both processes go on simultaneously and the general character of the flame depends on which predominates. This, in turn, depends upon surrounding conditions. Early mixing and preheating of hydrocarbons and air, plus time for the oxygen to enter the hydrocarbon molecules, favour hydroxylation. Rapid heating, and lack of mixing time, favour thermal decomposition.

Principles of Combustion

4.8 In order to burn fuel it must be in a gas form. The ability of some fuels to burn more readily than others depends on how easy it is to turn that fuel into a gas.

Having provided the gas, either a fuel that is normally gaseous or a gas given off from a solid or liquid fuel, it is now necessary to mix the gases thoroughly with oxygen, so that the chemical reaction of combustion can take place. In order to commence combustion we have to raise this mixture to an ignition temperature and hold it there. If such a mixture is heated gradually, the rate of chemical combustion increases until a point is reached where the reaction no longer depends on heat from an outside source, and practically instantaneous combustion occurs.

The lowest temperature at which this takes place is called "ignition temperature". It may be defined as a temperature at which heat is generated by the reaction faster than it is lost to the surroundings, and combustion

thus becomes self-propelling. Below this point the "gas-air" mixture will not burn freely and continuously unless heat is supplied from an outside source. From this it will be seen that to provide the conditions necessary for combustion to take place, and continue to take place, there must be sufficient temperature to maintain combustion, sufficient time for the oxygen to combine with the combustible elements in the fuel, and the oxygen must be well mixed with those elements. Thorough mixing of the gas and air can be achieved by adequate turbulence in the combustion chamber.

Within the combustion zone fuel must be vaporized, mixed with air, ignited, and the reactions between the fuel and oxygen carried to completion.

Turbulence is essential as this causes the fuel and air to swirl and eddy in irregular paths before the gases reach the outlet. This gives an increase in time for combustion and mixing of the fuel elements and oxygen, and, as the fuel and air move past each other at high velocity, it sweeps away already formed combustion products from the particles of the fuel and exposes fresh surfaces for further chemical reaction. This process can be summarized as:

TEMPERATURE - TIME - TURBULENCE

(The Three T's)

Primary and Secondary Air

4.9 Primary air is the air that first mixes with the fuel. Secondary air is the additional air required to complete the process of combustion. The methods of providing primary and secondary air vary with the type of fuel being burned and the equipment burning it, but at this stage, let us look at the factors involved in supplying primary and secondary air in burning coal on a fuel bed (Figure 4-1).

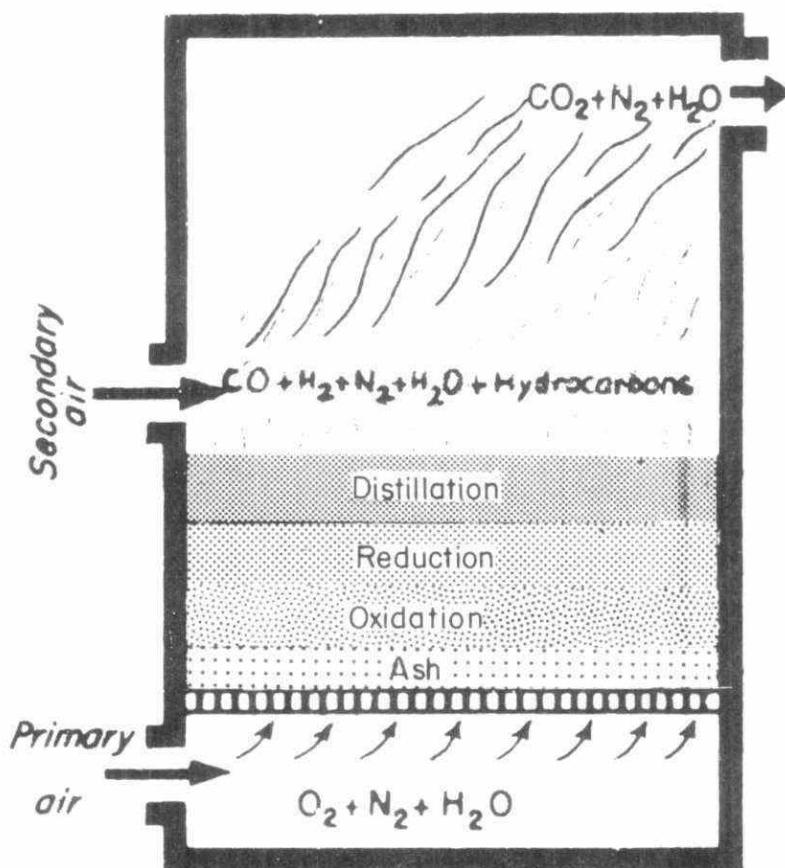


Fig. 4-1 Simplified fuel bed shows four zones

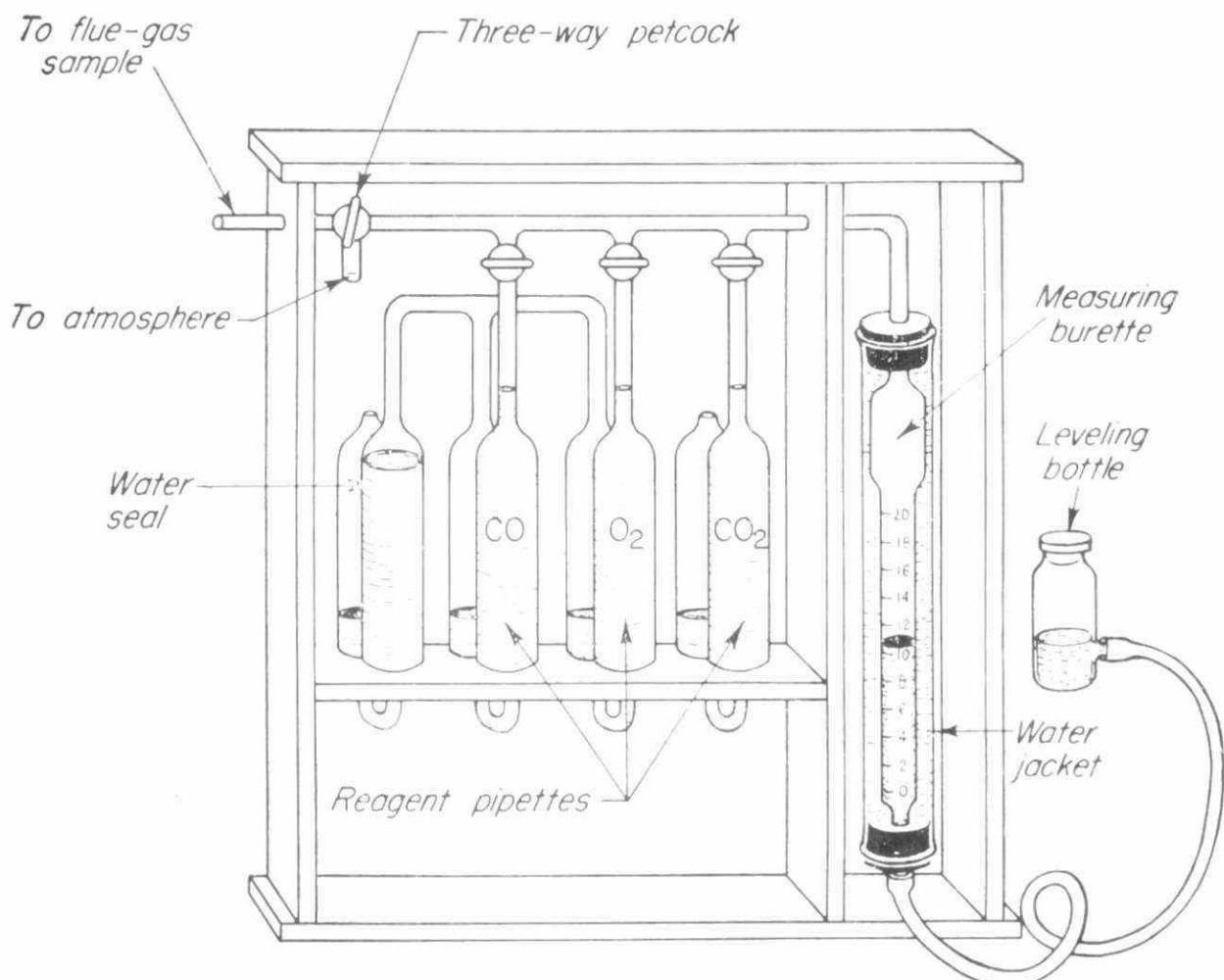


Fig. 4-2 Orsat apparatus.

You will see that the air which flows up and through the fuel bed is called primary air; that entering the furnace above the fire is secondary air. In this type of firing the fuel is fed to the furnace by being pushed, thrown or dropped onto a grate in the high temperature region of the furnace. The primary air flows upwards through the grate and through the fuel bed that is formed on the grate. The green coal is heated, the volatile matter distills off, and the coke is left on the grate. Coke burns to a mixture of carbon monoxide and carbon dioxide and the remainder is the ash.

The oxygen that is in the primary air is practically all used up on its passage through the fuel bed, and the volatile matter of the coal and the carbon monoxide from the coke still requires to be burned over the top of the fuel bed. In order to do this more oxygen is required, and this is provided by the secondary air supply. So, we can say that the flow of primary air through the fuel bed controls the rate of burning, but the secondary air completes the process of combustion.

Secondary air must be closely regulated according to the fuel used. In the case of the solid fuel furnace we are considering, the amount of secondary air would vary with the type of coal being burned. In the case of bituminous coal, which gives off a great deal of volatiles (gas), much more secondary air would be required than if anthracite was being burned, for anthracite gives off relatively little volatiles.

4.10 Looking at Figure 4-1, we see that the fuel bed can be divided into four parts, or zones, one above the other. In actual practice, these levels would vary in size and shape depending on the grate type and method of fuel feed, but let it be assumed that the zones are level and extend across the grate.

From the top down we have:

1. Distillation
2. Reduction
3. Oxidation
4. Ash

At the top, the green coal receives the furnace heat, volatile matter distills off and the coal reduced to coke works down as lower levels burn out and fresh coal is added.

In the oxidation zone the coke is burned to carbon dioxide with the primary air rising through the bed. This carbon dioxide now rises up through the level above and is partly reduced to carbon monoxide by contact with the hot coke. The bottom layer of ash protects the grate from excessive heat.

Following the process from the underside of the grate, as the air passes up through the fuel bed, we see that as the air passes through the oxidation zone, the coke which is largely carbon, combines with the oxygen to form CO_2 . As the CO_2 continues upward through the reduction zone the CO_2 combines with carbon to form carbon monoxide. The carbon monoxide then passes above the fuel bed and mixed with the hydrocarbons given off in the volatiles, from the distillation zone, and it is this mixture which receives the oxygen contained in the secondary air and combustion is completed, resulting in flue gases containing carbon dioxide, nitrogen and water vapour.

Excess Air

4.11 We have now seen that combustion is the combination of the burning material with oxygen, and so it can happen only when oxygen is present. Chemically coal consists mostly of carbon, and when coal burns the carbon combines with oxygen in the air, the product being carbon dioxide. We say

"oxygen in the air" because, of course, air is a mixture containing, as we know, approximately 21% oxygen, 79% nitrogen, by volume.

Supposing we burned pure carbon with air, the 21% oxygen would combine with the carbon and would show a flue gas containing 21% CO_2 . Coal, however, is not pure carbon, it contains some hydrogen, which burns to form water, using up some of the oxygen in the air. As a result, the perfect flue gas formed when coal is burned in the least possible volume of air, contains less than 21% CO_2 . In the case of a typical bituminous coal, the perfect flue gas would measure about 18% CO_2 .

In practice it is not possible to burn coal in a boiler plant and get as much as 18% CO_2 in the flue gas, as that would require perfect mixing of air with fuel; the actual result of supplying only the minimum of air would be that some of the coal could not get enough oxygen to burn completely. This would lead to the production of smoke and carbon monoxide, instead of carbon dioxide, and the loss of a great deal of heat up the stack.

To avoid the danger of such heat losses, an excess of air is always supplied.

If again we look at our 100 parts of air containing 21 parts oxygen and combining with carbon in a bituminous coal, we see again that we get 18% CO_2 . If we add to that 100 parts of air another 50 parts of air, we see that our resulting 18%, or 18 parts in 100, of carbon dioxide, now becomes 18 parts in 150 parts, in other words reduced to a percentage our carbon dioxide is now 12% with 50% excess air. We can sum this up by saying, if a typical bituminous coal is burned with 50% excess air, the result is a flue gas with 12% CO_2 . This is a good standard of

performance in the ordinary coal-fired boiler house. Notice that in all these figures the nitrogen content of the air is ignored, as it plays no part in the process of burning, it is only a passenger heated in the furnace and passing through the boiler to the stack. However, it carries heat away with it, and to keep this loss of heat as small as possible, the amount of air supplied to the furnace must be carefully controlled.

It has just been said that 12% CO_2 represents good practice in the ordinary boiler burning coal. Although this means supplying 50% excess air, it is wiser to do that and to make sure all the gases are completely burned. Incomplete burning could cause greater heat losses than 50% excess air.

Supposing that the CO_2 falls to 9% (this will happen if the excess of air is 100% instead of 50%). Heating the extra air will cause a large loss of heat up the stack. If the CO_2 is as low as 6%, four times as much excess air is being supplied as there should be. The guide then, to the amount of excess air being supplied, is the CO_2 content of the flue gases. The lower the CO_2 reading, the greater the amount of excess air.

Typical percentages of CO_2 and corresponding percentages of excess air for various fuels are shown in Table 4-1.

Now it can be seen why the CO_2 readings are so important. A fall of 1 point in the CO_2 does not sound like very much, but the table shows that it means an enormous increase in the amount of excess air drawn through the boiler. The heat that this excess air carries away up the stack is by far the biggest waster of fuel.

Table 4-1

PERCENTAGES OF CO₂, O₂ AND THE CORRESPONDING PERCENTAGES
OF EXCESS AIR

Fuel	CO ₂ & O ₂	Percentage Excess Air					
		0	20	40	60	80	100
Anthracite	CO ₂	19.5	16.0	13.8	12.0	10.7	9.6
	O ₂	0.0	3.5	6.1	8.0	9.4	10.6
Bituminous	CO ₂	18.6	15.5	13.2	11.5	10.1	9.2
	O ₂	0.0	3.5	6.0	8.0	9.5	10.6
Fuel oil	CO ₂	15.5	12.6	10.6	9.3	8.2	7.4
	O ₂	0.0	3.7	6.4	8.1	9.6	10.8
Natural gas	CO ₂	12.2	10.0	8.5	7.5	6.5	5.7
	O ₂	0.0	4.0	6.5	8.5	9.9	10.9

If the flue gas contains CO, add the sum of the CO₂ percentage to half the CO percentage to get the resultant CO₂. Thus, if the CO₂ reading is 12% and the CO 2%, the equivalent CO₂ percentage is $12 + \frac{1}{2} \times 2 = 13\%$.

DRAUGHT

4.12 The basic requirements for complete combustion are that air and fuel be brought into contact under the right conditions and the right proportions, and that the products of combustion be removed when they are formed. To do this there must be a flow of gases through the system, and this is the function of draught.

There are four forms of draught:

1. Natural
2. Induced
3. Forced
4. Balanced

1. Natural Draught

4.13 Natural draught is produced by the chimney alone, or rather by the difference in weights of the column of gases in the chimney and the column of air outside. The hot gases in the chimney are lighter and so are displaced up the chimney by the cold heavier air being forced through the furnace. The hotter the furnace gases are the greater is the draught they produce, and a high chimney creates more draught than a low one.

2. Induced Draught

4.14 This is extra draught created by a fan placed between the boiler and the chimney. The fan draws the gases through the boiler plant and discharges them into the chimney. The speed of the fan can be adjusted to provide the right amount of air.

3. Forced Draught

4.15 This is extra draught created by a fan which supplies air under pressure to the furnace, forcing air through the fuel bed, boiler and flues.

Steam jets are sometimes used in place of a fan to create forced draught. In this system, a jet of steam is discharged at high speed into a tube under the fire bars. This causes air to flow through the tube, the air and steam mix and force their way through the fuel bed. This system is more properly called assisted draught.

4. Balanced Draught

4.16 In this system, air is forced in by a pressure fan and the products of combustion withdrawn by a suction fan in such a way as to leave zero to slight suction over the fire.

4.17

Advantages of Mechanical Draught

1. Increased evaporative power
2. Better combustion - less excess air
3. Reduced size of boiler
4. Lower grade fuel may be used
5. Control of combustion
6. Control of smoke emission
7. Chimney height no longer essential for draught
8. Sufficient draught to use economizers, heaters, etc.

Draught Control

4.18 The draught required to burn fuel efficiently depends upon:

1. The kind of fuel used
2. The rate at which it is required to burn the fuel
3. The design and condition of the plant

If the resistance to the travel of gases through the boiler and flues is high, more draught is needed. The resistance of the flues can be kept to a minimum by keeping them clean; dirty flues hinder the flow of the flue gases. This also applies to economizers.

Air infiltration or leakage into flues through faulty furnace fittings, defective brickwork, badly fitting dampers, etc., uses up some of the draught and cools down the chimney gases, lessening the draught available to pull air through the fuel bed.

Draught Gauges

4.19 The supply of air is controlled by watching the draught gauge and by adjusting the dampers or mechanical draught controls.

The simplest form of draught gauge is a glass tube bent to form a "U". This is filled with water up to a zero mark on a scale behind the tube. One leg of the "U" tube is connected to a suitable point in the boiler flue, and the other leg is left open. The pressure of the atmosphere being higher than the pressure in the flue will push the water down in one leg and cause the water to rise in the other leg. The difference in the height of the water in the two legs is a measure of the draught available. If the difference in height is $\frac{1}{2}$ " then the draught is $\frac{1}{2}$ " water gauge.

If the "U" tube, or draught gauge, is connected below the grate of the forced draught furnace, the water in the leg open to the atmosphere will rise instead of fall. The reason is that the pressure under the grate is higher than that of the atmosphere. "U" tube gauges cannot be read to the fine limits required for some purposes, and then other types of draught gauges are used, such as an inclined tube, or a pointer gauge which have magnified scales.

Draught gauges should be connected to furnaces, flues or ducts so that the end of the open tube is at right angles to the flow of gases or a correct reading will not be

obtained. If the open end of the tube in the flue faces the flow of gases the reading will be too low, if it faces in the opposite direction the reading will be too high. Draught gauges should be mounted in such a position that they can be easily read by the operator. The best place is near the damper control or mechanical draught control point.

Flue Gases

4.20 Incomplete combustion may result in the presence of carbon monoxide, carbon, hydrogen, or unburned hydrocarbons in the flue gas, resulting in soot and inefficient utilization of the heat contained in the fuel.

Other factors can influence achieving good combustion, but generally speaking it is the control of excess air which is important, and the amount of air to be admitted is determined chiefly by the flue gas analysis.

When we discussed excess air earlier, we saw that the guide to the amount of excess air being supplied is the CO_2 content of the flue gases, the lower the CO_2 reading the greater the amount of excess air. We also saw that the heat that this excess air carries away up the stack is by far the biggest waster of fuel. The waste depends not only on the amount of excess air in the flue gases, but, of course, on how hot those flue gases are when they leave the boiler. Two measurements are required to determine this heat loss - the amount of CO_2 the flue gases contain, and their temperature.

High temperatures in the flue can only mean that for one reason or another the hot gases are not getting a chance to give up enough heat to the water in the boiler. The main reason is that too much excess air is used. This increases the volume of gases produced and they are too short a time in the boiler to give up their heat. Overloading the boiler, that is to say forcing the fire, has the same effect. A further reason is that the boiler plates are too dirty, either with soot on one side or with scale on the other.

Sampling

4.21 The chief difficulty is to get a representative sample. The sample should be taken from the uninterrupted main stream, not from dead ends or areas where eddies occur. Particular difficulty is experienced where two streams of

gases are involved, as these may be slow to mix. In such a case a cross section of the gas stream may have to be obtained using bundles of tubes of different lengths inserted into the flue, the longest extending to the centre.

Generally, however, the sample is taken at a test point hole in the breeching, close to the point of exit of the flue gases from the boiler proper.

Measurement of Composition of Flue Gases

4.22 The most commonly used apparatus for obtaining a complete flue gas analysis is the Orsat set (Figure 4-2).

The apparatus consists of a water-jacketed burette graduated into 100 divisions; 2, 3, or 4 pipettes containing various absorbents each with a displacement vessel, and a stop cock connecting them by tube to the burette; an aspirator bottle filled with water and connected by tube to the bottom of the burette.

The flue gas sample is drawn into the burette by first raising the aspirator bottle, so filling the burette with water, then opening a three way cock connecting the burette to the gas stream and lowering the aspirator, when the gas is drawn into the burette through a smoke filter. This is repeated two or three times to purge the line, the gas being blown out to the atmosphere by suitably positioning the three way cock.

When finally gas filled, adjust the water level in the burette to the zero mark, when the level in the aspirator and the burette is the same, ensuring that the sample is at atmospheric pressure. The first pipette in the series contains a solution of caustic potash which absorbs CO₂, and its cock is now opened and the bottle lifted so passing the gas into the pipette. The gas is then returned to the burette by lowering the aspirator. Repeat

two or three times and then close the pipette cock, equalize the levels in the bottle and burette, and take the burette reading which represents the percentage by volume of CO_2 in the gas.

Oxygen volume can then be found by similar action with the second pipette, then carbon monoxide with the third pipette. The fourth pipette, where present, is for obtaining the hydrogen sulphide content. Pipettes 3 and 4 may be omitted in some sets where it is simply desired to find the CO_2 and/or oxygen content.

The solutions used for absorption of the various gases are potassium hydroxide for CO_2 , pyrogallol for oxygen, cuprous chloride for carbon monoxide, and cadmium chloride for hydrogen sulphide.

The CO_2 content of the flue gases can also be measured with the Fyrite apparatus. This operates on the same principle as the Orsat apparatus. A sample of the flue gas is forced into the apparatus by means of a rubber bulb. When the Fyrite is turned upside down the sample is bubbled through a solution of caustic potash. This is done several times, finishing with the apparatus the right way up. The liquid will have risen in the centre tube and will show on the scale how much CO_2 there was in the sample.

When continuous readings are needed, chemical or electrical methods are used to show how much CO_2 there is in the flue gas, on an indicator or recorder mounted near the front of the boiler.

Measurement of Temperature

4.23 The temperature can be measured by using either a mercury-in-steel thermometer, or a thermo-couple and temperature indicator.

The mercury-in-steel thermometer consists of a

steel tube sealed at one end and connected to a dial gauge at the other end. The steel tube which is filled with mercury is placed in the flue.

When it is heated by the hot flue gases, the mercury expands and moves a pointer in the dial gauge to indicate the temperature.

Temperatures can also be measured electrically by means of thermo-couples and a temperature indicator. The stem of the thermo-couple is placed in the flue and from the head a cable is taken to the temperature indicator which should be placed near the front of the boiler where it can be easily read.

SUBJECT:

TOPIC: 5

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

BOILERS

OBJECTIVES:

The trainee will be able to:

1. Describe the function of a boiler;
2. Give the two main types of boilers and describe how they differ;
3. Explain what a waste heat boiler is, and describe its industrial application;
4. Explain why soot removal from heating surfaces is necessary, and describe how it is done.

BOILERS

Types and Uses

5.1 A steam boiler is a vessel which is used to turn water into steam by means of heat.

A boiler then, is simply a device in which heat is transferred from gaseous products of combustion to water, causing the water to evaporate and form steam. To fulfil its function the boiler must be capable of containing the water and the steam at the desired pressure, transferring the heat from the hot combustion gases to the water in such a manner as to preclude over-heating and over-stressing of the pressure parts, and delivering steam of satisfactory dryness with few, if any, solids carry over.

5.2 Boilers generally may be categorized as being of the fire-tube or water-tube type. Fire-tube boilers are boilers with straight tubes that are surrounded by water and through which the products of combustion pass. The tubes are usually installed within the lower portion of the shell below the water line. Water-tube boilers are boilers in which the tubes themselves contain steam or water, the heat being applied to the outside surface. The two main classifications are further broken down into many types, classified on the basis of use, pressure, materials, size, tube shape and position, firing, heat source, fuel, circulation, furnace position, furnace type, general shape, manufacturer's trade name and many other special features.

Fire-tube boilers are principally used for heating systems, for industrial process steam or as portable or mobile boilers. They are produced in sizes

up to about 20,000 lb. steam per hour as we know them, and to about 200 psig steam pressure. The fire-tube boiler serves its chief use where steam demands are relatively small.

The installed cost of a fire-tube boiler is relatively low and generally considerably less than that of a corresponding drum type water-tube boiler.

For pressure above 150 psig and capacities over 15,000 lb. steam per hour, the steel water-tube boiler is used almost exclusively. The water-tube boiler is composed of drums and tubes, the tubes always being external to the drums and serving to inter-connect them. The drums are used for storage of water and steam. As they are not required to contain any tubular heating surface they can be much smaller in diameter than a fire-tube boiler shell, and can, therefore, be built to resist high pressures. The tubes contain most of the heating surface.

Horizontal Return Tubular (H.R.T.) (Figure 5-1)

5.3 The horizontal return tubular boiler has been more widely used in the past perhaps than any other type of fire-tube boiler, for pressures up to 250 psig and in sizes ranging from 1,000 - 15,000 lb/steam per hour. It has been exceedingly popular for industrial process steam applications and small industrial plants. Many H. R. T. boilers are still used for heating large buildings and for factory process steam production, but they are rapidly being supplanted by other types requiring less erection labour.

The H. R. T. boiler consists of a cylindrical

FIG. 4. Horizontal Return Boiler.

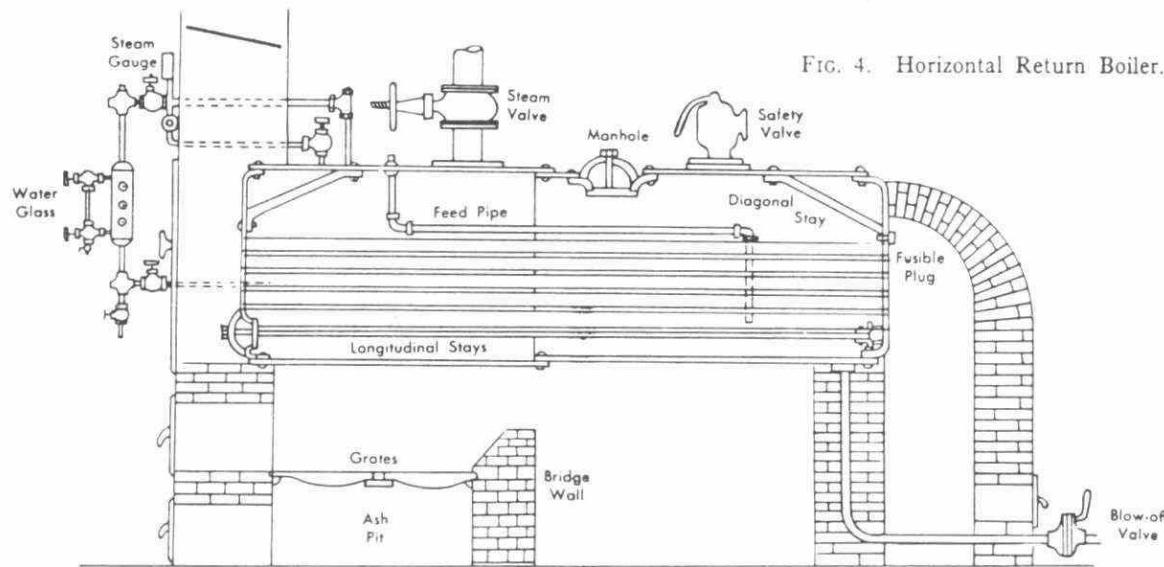


Figure 5-1 Horizontal Return Tubular Boiler (H.R.T.)

shell with flat enclosures between which are supported a large number of 3" or 4" fire-tubes. In recent years the use of smaller diameter tubes has improved the boiler performance by permitting installation of additional heating surface. The boiler is suspended above an external brick set furnace, the grates or combustion area being located directly below the front end of the shell. Although the boiler is usually hung from suspension rods it may be bracketed and supported by furnace side walls. Occasionally the furnace setting is steel encased and insulated to reduce the refractory wall thickness. Fuel is burned under the front portion of the shell and flames and hot gases play against the bottom of the shell, pass over the bridge wall, and sweep its full length to the rear of the setting. Here they enter the horizontal tubes returning to the front of the boiler, and then pass through the smoke box discharging to the breeching.

Packaged Boilers (Figure 5-2)

5.4 The packaged boiler has found wide application since World War II in every field requiring boilers except large central station units. Practically all major manufacturers are now offering some form of standardized factory assembled unit.

The one piece unit incorporating firing equipment, controls and auxiliaries is quickly installed at a cost competitive with, or lower than that of, equivalent field assembled conventional equipment.

The one piece packaged boiler is completely shop assembled with:

1. Fuel burner (usually oil or gas or oil/gas)

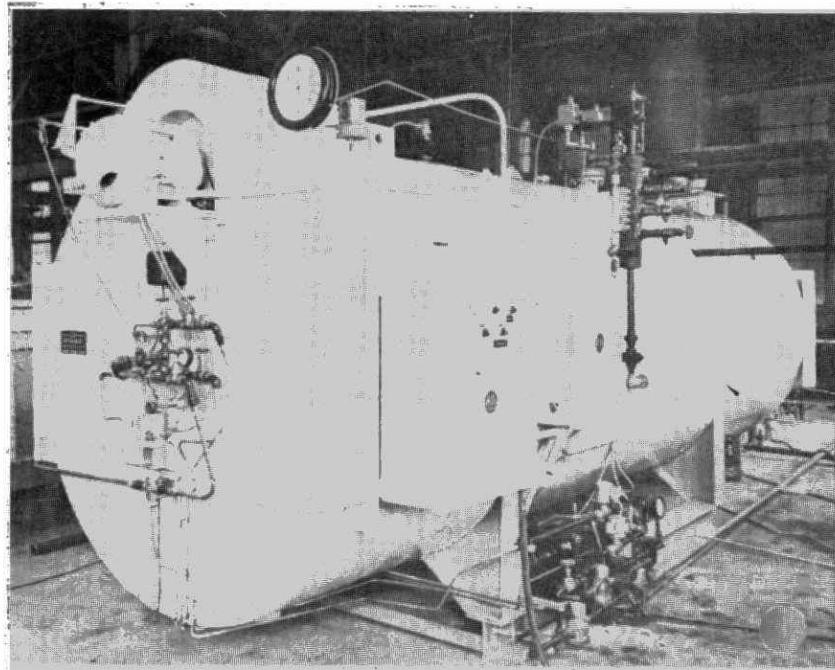


Fig. 5-2 4 pass Scotch Marine Fire Tube
Packaged Boiler

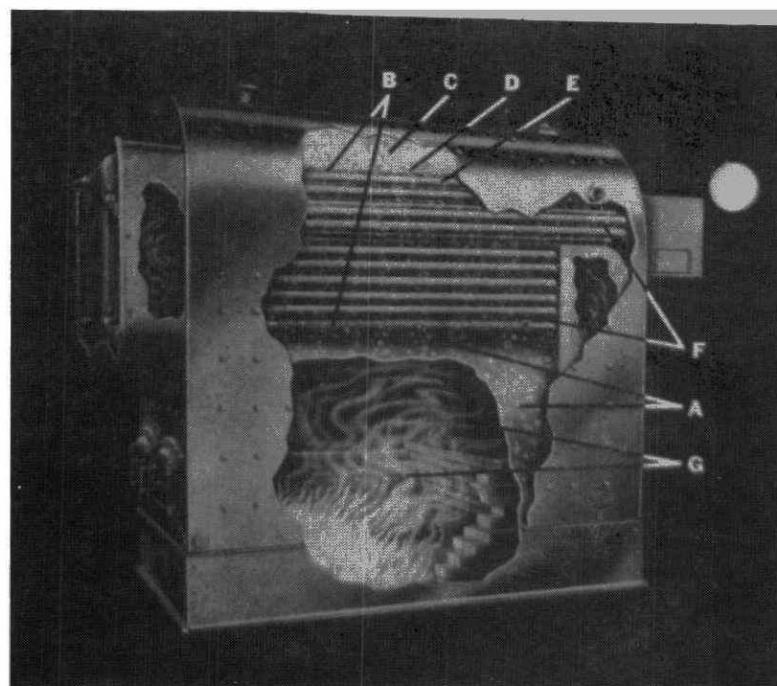


Fig. 5-3 Waterleg Compact FB

2. Mechanical draught system (forced or induced)
3. Condensate return and feedwater make up system
(including tank and pump)
4. External insulation (usually with casing or jacket)
5. Refractories
6. Trim
7. Control panel
8. Soot blower (if specified)
9. Oil pre-heater (if necessary)
10. Interconnecting piping and complete wiring

It is mounted on a structural steel base ready to be skidded or lifted into place on a simple foundation.

The packaged boiler is available in many versions:

- (a) Packaged residential heating boiler (steel fire-tube boiler, copper tubular boiler, cast-iron boiler)
- (b) Packaged commercial heating boiler (steel fire-tube firebox boiler)
- (c) Packaged Scotch fire-tube boiler
- (d) Packaged water-tube steam generator

(e) Packaged thermo liquid heaters and vaporizers

(f) Packaged positive circulation boilers

The only connections required for operation are those leading to sources of water, fuel, and electricity, steam and condensate return piping, and a stub stack for vent gases.

There are a number of advantages claimed for the packaged boiler. Probably the most important one is that responsibility for the entire unit is assigned to a single manufacturer, rather than to various component suppliers.

Standardized models provide the best possible operating economy because of high combustion efficiency. Also, the designer is permitted relative freedom if the boiler and its furnace are to be designed around a specific fuel burner.

The Compact Boiler (Figure 5-3)

5.5 The compact boiler is the most popular boiler for larger residences and commercial and industrial installations. It is a three pass boiler, including the firebox pass. The most common is the portable firebox type which requires a minimum of foundation work and is suitable for battery installation. Capacities range from 350 - 12,500 lb/ steam per hour.

The installed cost is economical and particularly for over firing this is an ideal boiler. It possesses the maximum heating surface per unit floor area of any of the conventional boilers with horizontal fire tubes.

It is a horizontal fire-tube boiler consisting of a shell with two passes of tubes, attached to tube sheets inside the enclosures.

The fuel is burned under the front portion of the shell, the products of combustion sweep over the full length of the lower half of the shell to the rear of the setting, where they turn and enter the first tube pass, travel to the front smoke box, reverse direction and travel to the second tube pass to the rear gas outlet, then discharge to the breeching.

Water-Tube Boilers (Figures 3-1 to 5 pp. 3-18 to 24)

5.6 As stated previously for pressures above 150 psi and capacities over 15,000 lb/steam per hour, the steel water-tube boiler is used almost exclusively. Some steel water-tube boilers are found in the low pressure (15 psi) heating field in the smaller sizes. Pressures in central station utility plant boilers go as high as 5,000 psi.

Steel fire-tube boilers become limited as capacity and pressure requirements increase. Large shell diameters require thicker plates to withstand the pressure and temperature stresses. Temperature differentials in the boiler create high stresses of indeterminate magnitude. These stresses combined with the effects of precipitates and other deposits have caused many boiler explosions. Because of its smaller component sizes and ability to accommodate expansion, the steel water-tube boiler is much more suitable for large capacities and high pressure through the inherent safety of its design.

The water-tube boiler is composed of drums and tubes, the tubes always being external to the drums

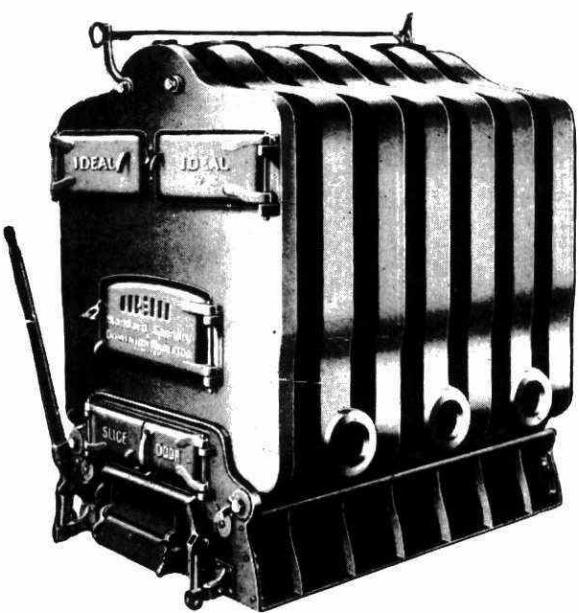
and serving to interconnect them. The drums are used for storage of water and steam. As they are not required to contain any tubular heating surface, they can be much smaller in diameter than a fire-tube boiler shell and can, therefore, be built to resist higher pressures.

Cast-Iron Boilers (Figure 5-4)

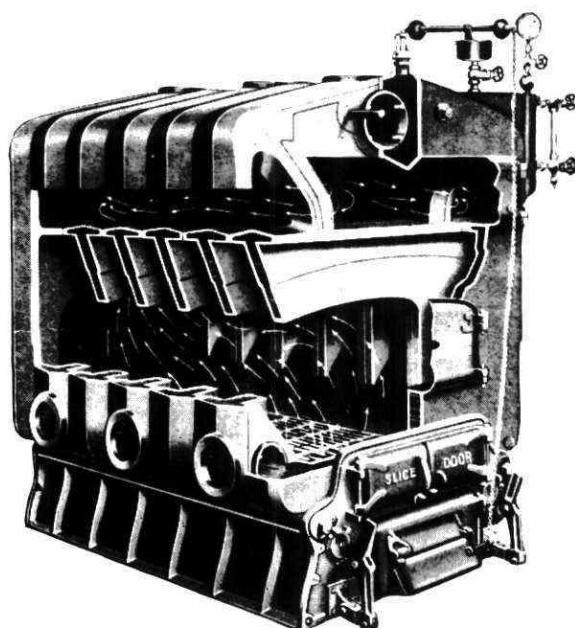
5.7 The cast-iron boiler is used primarily for low pressure heating system application - 15 psig for steam, and 30 psig for hot water (with certain exceptions at 40 psig) - such as are required in residences, institutions, commercial buildings and light industrial plants. It is also available, however, as a domestic hot water heater for operation at 120 psig.

Almost any type of automatic fuel burning equipment can be used with the cast-iron boiler. Because of large combustion chamber volume, and liberally sized flue passages, draught losses are low and chimney heights may be reduced accordingly. Cast-iron sectional (C. I. S.) boilers are comprised of vertical sections, each essentially a separate boiler, stacked like a loaf of sliced bread. The sectional boiler has the advantage of expandability, that is, it may be enlarged by adding sections and corresponding plate work. Its heating surface area is large in comparison to its water volume; steaming, internal water circulation and efficiency characteristics are excellent. Many installations have been in operation for thirty to seventy-five years.

When fuel is burned in the furnace, the combustion gases rise and enter the flue passages, circulate until they reach the smoke hood and then discharge to



36 Series Water Boiler



Sectional View of Dominion 36" Series Steam Boiler

**Cast-Iron Sectional Boiler
Fig. 5-4**

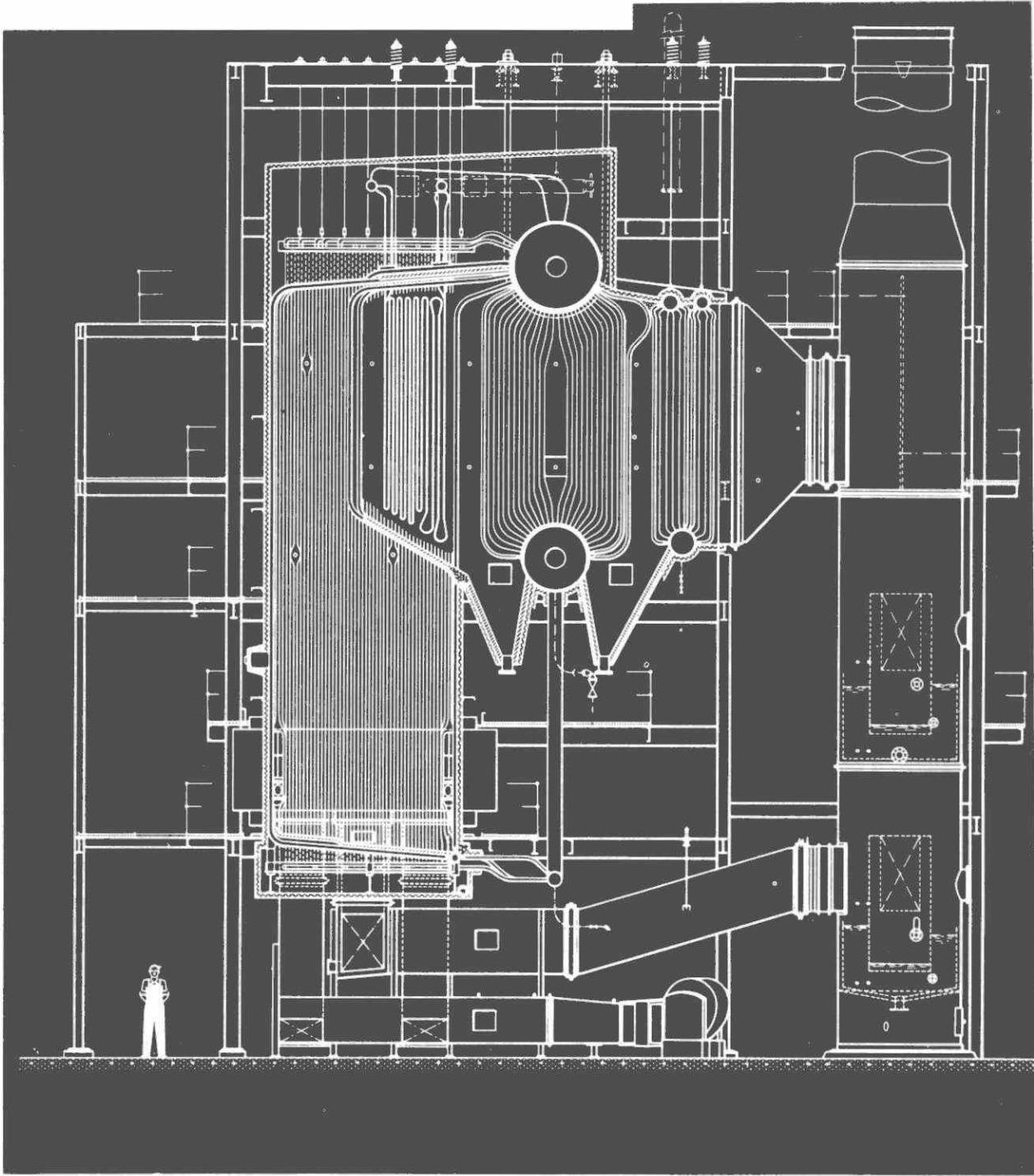
the breeching. Directed by the flue passages, they neither wander nor linger in the boiler. Each section has a water inlet at the bottom and a steam outlet at the top. Rather than circulating longitudinally along the sides of the combustion chamber, the water flows upwards through the water tubes to form the steam that is discharged at the upper nipple. Some wet base designs are built with water filled spaces that completely surround the bottom as well as the sides of the combustion chamber or ash pit.

Dutch Ovens

5.8 The dutch oven furnace is a primary furnace used to extend a boiler setting or furnace to obtain additional combustion volume. Built as an appendage in front of the boiler, the furnace is a refractory-lined masonry structure, containing a relatively wide combustion chamber, grates, and sometimes an ash pit. Usually the structure is encased in sheet steel that is supported on a structural steel framework. Occasionally tubes are built into the walls and water circulated through them to absorb heat. The exterior resembles an old-fashioned Dutch oven, hence the name.

Waste Heat Boilers (Figure 5-5)

5.9 Heat recovery from industrial process waste products or gases is often a necessity both from an economic and air or water pollution standpoint. All or part of the steam requirements of a plant may be supplied by waste heat boilers. Waste heat is perhaps a misnomer as a more appropriate term would be "by-product heat".



—Maximum continuous evaporation—85,000 lb/hr

Operating pressure—625 psig

Steam temperature—750 F

Waste regenerator gas weight—124,700 lb/hr

Waste regenerator gas temperature—1050 F

Carbon monoxide content—6.3 per cent by weight

Fig. 5-5 CO BOILER INSTALLATION in Canadian Refinery

Recovered heat may have the following sources:

1. Heat that originated as a necessary part of a process and would otherwise be discarded, such as from an open hearth furnace
2. Heat that is a by-product of a chemical process
3. Heat that is available from burning wastes, such as wood scraps

Wherever a process waste product or gas is continuously discharged at a temperature of 1000° F or higher, heat recovery should be considered. In addition to producing useful steam, the lowering of the flue gas temperature reduces maintenance of flues, fans and stacks. Often process material particles may be more completely recovered from the cooled gases. The more important waste fuels are: (1) blast furnace gas (2) coke-oven gas (3) fluid petroleum coke, and (4) black liquor.

Specific process requirements in the production of steel, copper, zinc, cement, paper and the like, have resulted in the design of various types of waste heat boilers.

Basically waste heat boilers are of the fire-tube or water-tube design, the boilers usually having a single pass arrangement that absorbs only convection heat from the gases. In the fire-tube type, the tubes are of smaller diameter and more closely spaced than in direct-fired applications. They are kept clear of deposits by a rotating-arm soot blower with the nozzles

directed toward the tube ends.

Large quantities of dust are found in waste gases available for steam generation but boilers can usually be kept in proper operating condition by dust collectors, pockets and hoppers and sometimes conveyors. Dust-laden gases require low velocities to minimize abrasion of the tubes.

Where heavy dust loadings are encountered, a water-tube type waste heat boiler is usual and is the most frequently used.

Waste heat boilers are used extensively in the steel industry; open hearth and continuous heating furnaces being usually equipped with waste heat boilers; and coke oven gas and blast furnace gas are used as waste fuels.

Where these gases are used as fuels, the burner requires special handling as both are extremely dirty. The burning equipment requires access for cleaning. All boiler services need extra provisions for soot blowing and washing.

Other applications for waste heat boilers are after cement kilns, ore roasters, lead and zinc smelters and, in the paper making industry, where black liquor (liquid waste from wood digesters) is used as a fuel.

Soot Removal and Soot Blowers (Figures 5-6 & 7)

5.10 Soot is an amorphous carbon and as such acts as an insulator when deposited on heating surfaces. Its removal therefore saves heat. In small plants scrapers and brushes attached to rods made of small pipe are used to remove soot and light incrustations of ash. In large plants some form of soot blower is used for this purpose.

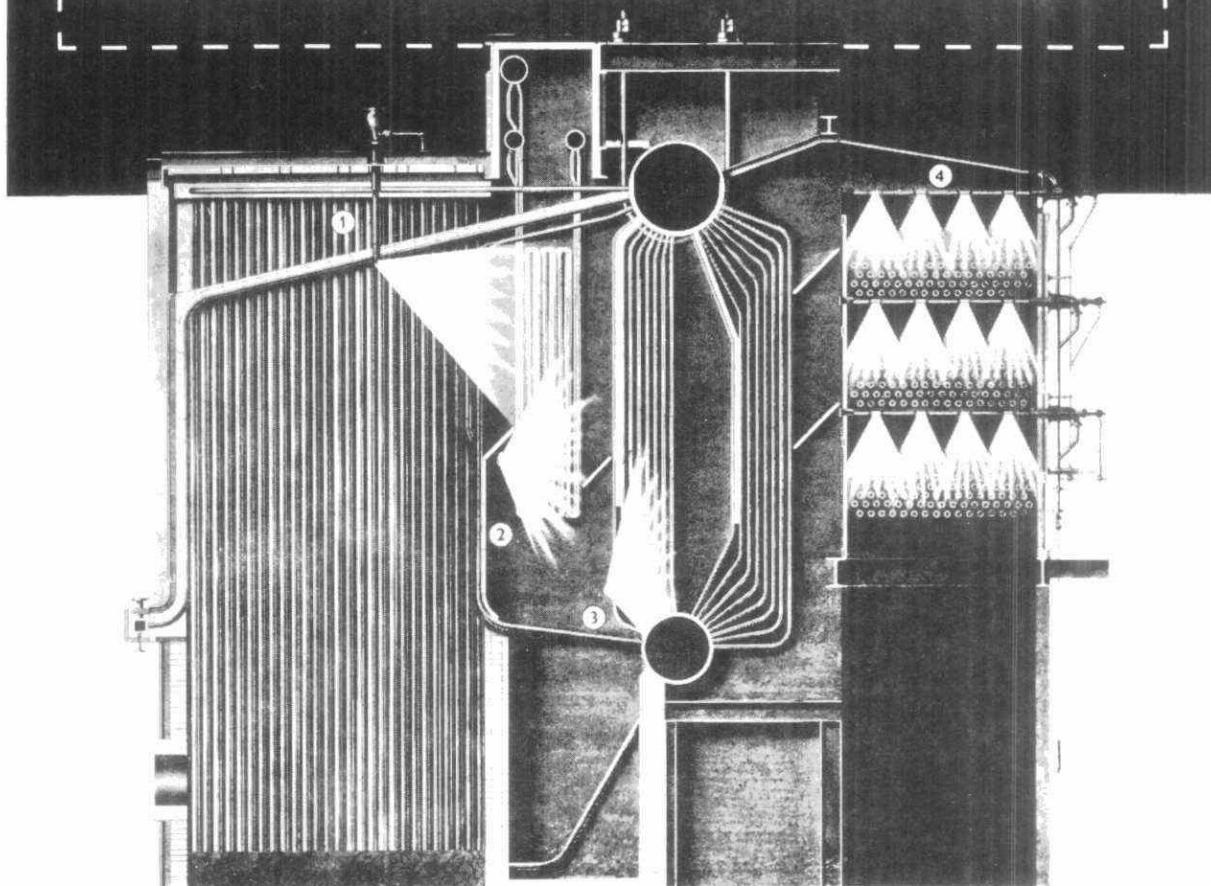
In the efficient soot blower, steam is expanded in a nozzle located in the blower head and attains a high velocity, thus drawing in a large volume of air. The combined blast of steam and air sweeps the tube efficiently.

A permanent installation of steam jets for the removal of soot is commonly used in large plants since the gain in economy more than offsets the expense. Cleaning the tubes with a hand blower is a disagreeable job and is likely to be neglected.

In water tube boilers, the mechanical soot cleaner consists essentially of a cleaning element which may be stationary or movable.

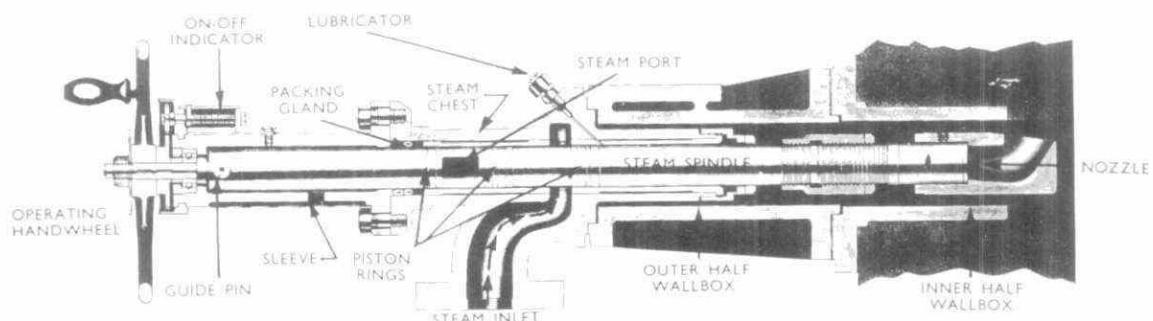
A typical soot cleaner as applied to a water tube boiler consists of one or more elements for each pass of the boiler setting. Each boiler is located above the tubes and at right angles to them and has steam nozzles arranged to direct the steam on the tubes along diagonal paths at 60 degrees to the horizontal. Steam is supplied to the elements by automatic valves. Each element is mounted on bearings and is provided with a chain sprocket, crank handle or air motor drive

A TYPICAL WATERTUBE BOILER SHOWING OPERATING POSITION OF VARIOUS TYPES OF CLYDE BLOWERS



This sectional drawing demonstrates the manner in which Clyde blowers are installed to maintain the boiler and economiser tubes in a clean condition.

Fig. 5-6



Sectional view Clyde Retractable Single Nozzle Blower.

Fig. 5-7

located outside the setting, so that the jets of steam can be made to sweep over the tubes and thus clean them more efficiently.

Soot displaced from the tubes may not be a problem if suitable equipment has been provided for its collection. In smaller plants it is most common to find no type of collection equipment and in larger plants the ash collection equipment will serve to collect soot as well.

Tubes will be blown on a regular basis depending on the fuel and operation in the plant. Kraft mill recovery boilers may blow boiler tubes twice per shift while other boilers may blow tubes only once per day. While the tube blower is in operation smoke in excess of the regulations may be visible from the boiler stack. For this reason, some plants may refrain from blowing tubes in the daylight hours. This may mean that the accumulation of soot on the tubes becomes too great for the collectors - if any - to handle, resulting in complaints of spotting on paint, automobiles, lawn furniture, swimming pools and washing, if left out overnight.

If smoke is to be controlled by operating personnel an electrical warning device should be installed in the system. Smoke being emitted passes between a light source and a photo-electric cell. The density of the smoke reduces the amount of light traversing the chamber. This varies the intensity of current at the receiving end which is relayed to a recorder on the main control panel. Practice is to

include also an alarm system to alert the operator if smoke density exceeds a predetermined value. Soot particles may settle out on the light source or receiver, setting off the alarm prematurely. For these reasons, every effort should be made to keep the receiver and transmitter clean. All too often the alarm system is found turned off because the operators find it easier to do this than to keep the alarm system in good working order.

Emissions from Boiler Plants

5.11 It is estimated in pulverized fuel operations that 75% of the ash in the coal will pass out through the stack in flocculent form unless it is trapped in some way.

Some ash catchers employ a cyclone or centrifugal separator connected with the stack, the gas being forced into it by an induced draught fan. Simple and compound cyclone collectors are extensively used. The former may be sufficient where the volume of flue gas is small, but the compound type (multicyclones) is required where large capacity is needed. In addition, gas washers and scrubbers are sometimes used. Due to the abrasive nature of coal fly ash, the cyclones will in time require repair or replacement due to the holes worn through them by the swirling ash.

In the larger stations electrostatic precipitators are used to remove fly ash from the flue gas. It consists of a chamber in which a voltage of from 75,000 to 100,000 volts creates a strong electronic field.

This precipitates small particles of ash on the wires as the gas passes through the chamber. When the wires become coated with ash, some means of removal such as rapping is necessary and the ash removed falls into a hopper beneath the unit. Since this equipment involves considerable space, the precipitator and electrical equipment is usually installed on the roof of the boiler house.

Dust collection equipment is dealt with in more depth under Topic: Concepts of Industrial Air Pollution Control.

Ash disposal may present other problems with secondary dust emissions occurring during the loading of trucks, haulage and dumping at the disposal site. Solutions to these problems are obvious. The loading operation can be covered in, dust proof covers provided for the truck boxes, and the dumping area screened or wetted down and covered with coarser material.

SUBJECT:

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

TOPIC: 6

MECHANICAL STOKERS

OBJECTIVES:

The trainee will be able to:

1. List the three main types of mechanical stokers;
2. Describe the operation of each type of mechanical stoker;
3. List the general causes of smoke and fly-ash emissions from mechanical stokers.

MECHANICAL STOKERS

- 6.1 Mechanical Stokers fall into three main types:
1. Overfeed
2. Underfeed
3. Chain-grate

1. Overfeed Stokers (Figure 6-1)

6.2 These are usually known as spreader or sprinkler stokers and they imitate the spreading method of hand firing. Coal falls from a hopper onto a feeder which throws fuel all over the bed by means of shovels, flippers or rotary distributors. In the case of the stoker illustrated in Figure 6-1, the fingers of the revolving drum throw the coal out in arcs, the fine coal burning in suspension and the large pieces burning on the grates, which may be of a stationary or dumping type. Air is supplied through the holes in the grates which are covered with a thin fuel bed. Forced draught is needed with this type of stoker and it is particularly liable to cause grit emissions.

As a large proportion of the coal from spreader stokers is burned in suspension, the temperature in the combustion area above the fuel bed is extremely important, and designs incorporating arches of refractory are less likely to have smoke problems. Pre-heated air also assists in this direction, particularly at low loads, but the grate material used may limit the amount of pre-heat that can be permitted without excessive grate maintenance.

Coal sizing is also important, as over-sized coal particles on a thin fuel bed, which we have with spreader stokers, can produce a local condition of inadequate air on the surface of the particles, resulting in the formation of smoke. Coal size 3/4" to 1 1/2" with not more

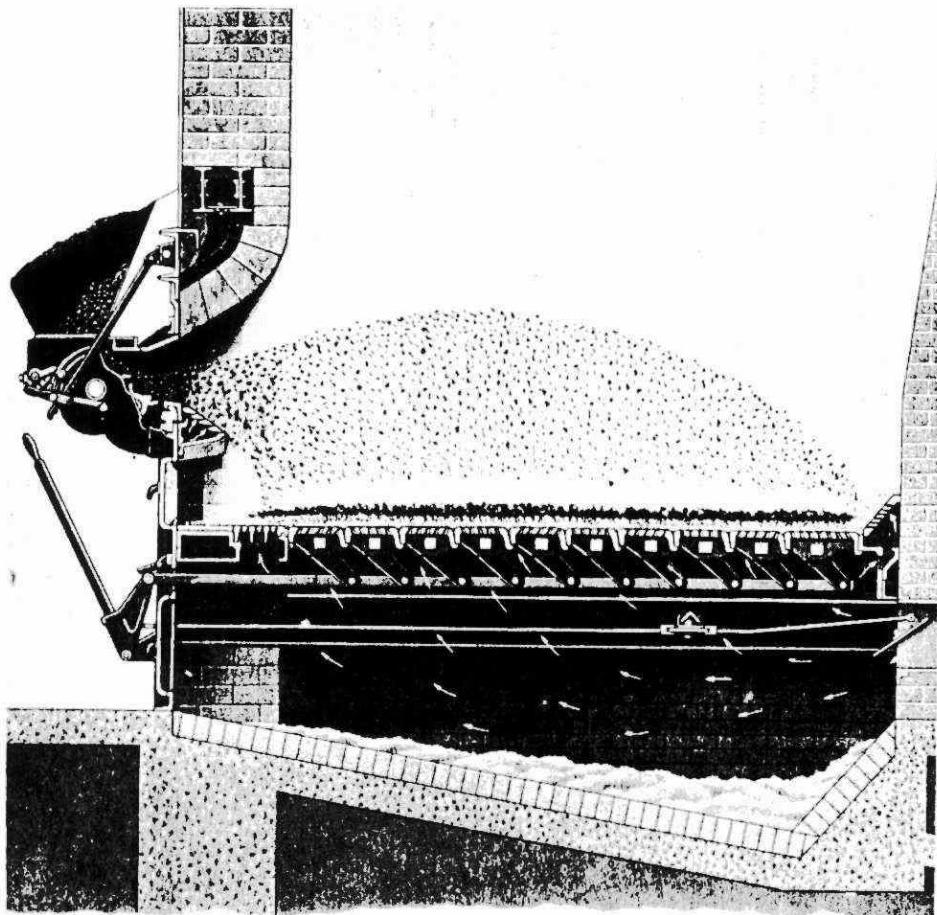


Figure 6-1 Spreader Stoker

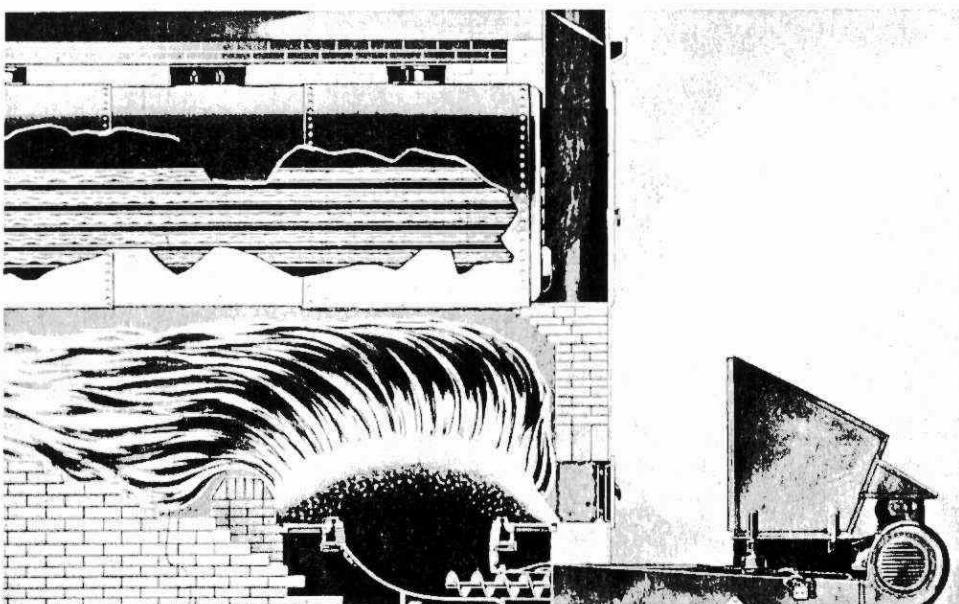


Figure 6-2 Underfeed Stoker-Screw Type

than 50% slack is probably the best combination for these stokers, but it is necessary to avoid size segregation.

It is also important to maintain a thin fuel bed, as too thick a fuel bed results in clinkering, which shuts off the air supply from large areas of the grate, creating smoke. For this reason also, consideration must be given in the use of spreader stokers to the firing of coal with non-caking characteristics.

Again, because of the method of combustion, with this type of stoker the use of overfire air is very important for producing turbulence, and the use of pre-heated air in this connection will avoid any danger of reducing the temperature of the gases at this critical point.

Turbulence created by overfire air can also be used to reduce substantially the fly-ash carry over which can be a problem with this type of stoker, particularly at high burning rates, which mean high average velocities of air through the fuel bed.

Without dust collectors, fly-ash emission rates with these stokers would pose a problem. The position is further aggravated by the use of cinder re-injection. Where total re-injection is practised, collector efficiency has to be extremely high.

Operating Problems and Remedies - Overfeed

6.3 Symptom - Excessive fly-ash discharge

<u>Probable Cause</u>	<u>Remedial Action</u>
Excessive fines in coal	Check coal handling equipment for cause of segregation of fines; Check coal supply for source of excessive fines.

Overloaded dust collector	Clean dust collectors and dump hoppers more frequently on regular schedule; with fly-ash and re-injection, check re-injection system; consider discontinuing re-injection.
Excessive furnace draught.	Check stack dampers; check automatic combustion controls; check thickness of fuel bed.
Excessive under grate air.	Check forced draught fan damper; check automatic combustion controls.
Maladjustment of coal feeders.	Check stoker setting to provide even coal distribution and level fuel bed.
Maladjustment in fly-ash re-injection system.	Check re-injection system for obstructions, operating pressure, nozzle wear, and alignment.
Inadequate fly-ash collection.	Check and clean dust collector and dump hoppers; also check by-pass dampers, if any.
Fly-ash re-injection from dust collectors.	Discontinue re-injection.

6.4 Symptom - Chimney Smoke

<u>Probable Cause</u>	<u>Remedial Action</u>
Fuel bed too thick.	Reduce amount of coal being fed; remove ash by more frequent cleaning; check size for excessive coarse sizes.
Improper distribution of forced draught fan damper.	Check undergrate baffles, seals and zone dampers for leakage and setting.
Improper adjustment of forced draught fan damper.	Check forced draught fan dampers and automatic combustion controls.
Clogged ports or closed damper on over fire air system.	Clean ports; check damper on over fire air system; also check operating pressure, jet alignment and blower.
Inadequate overfire air system.	Increase number of jets, and if necessary blower capacity; check location of jets (should not be more than 24" above grate).
Low steam load.	Increase load by shutting down other units, if any; or shut down other stoker feeders on multi-unit stoker.

Poor distribution of coal caused by maladjustment or wear of feeder parts.	Check stoker setting; balance setting on multi-unit boilers; replace worn parts as necessary.
Raw coal build-up on side waterwall ledge.	Rake raw coal away from waterwalls; check stoker setting; check stoker feeder parts for wear and replace as necessary.

2. Underfeed Stokers (Figures 6-2&3)

6.5 Underfeed stokers may be classified under two general types, those that have a coal feed mechanism employing a screw feed (Figure 6-2) and those that employ a ram or plunger (Figure 6-3).

The screw feed type comprises a hopper, the base of which communicates by a pipe with a retort in the furnace; the pipe contains a feed screw which by rotation advances the fuel to the retort. As the coal rises in the retort it approaches the incandescent surface of the fuel bed; the combustible gases are thoroughly mixed with the proper quantity of air introduced through tuyeres at the top of the retort; the mixture of gases and air must then pass through the hot fuel bed and complete burning takes place. As the fuel cokes and then burns the ash is pushed over the sides of the pot. Most small units of this type in use are limited to "off" and "on" operation, but a modulating stoker control unit is now available which can be adapted to most underfeed screw-type stokers. It is a two position control that is installed to operate in conjunction with the existing stoker transmission. As the boiler load changes, the flow of coal and air to the boiler is changed accordingly.

The control is actuated by a temperature or steam pressure change which is pre-determined so that the flow of coal and air is reduced before the boiler reaches its operating limit; the change in coal rate is accomplished by a change in gear ratio and the regulation of the air

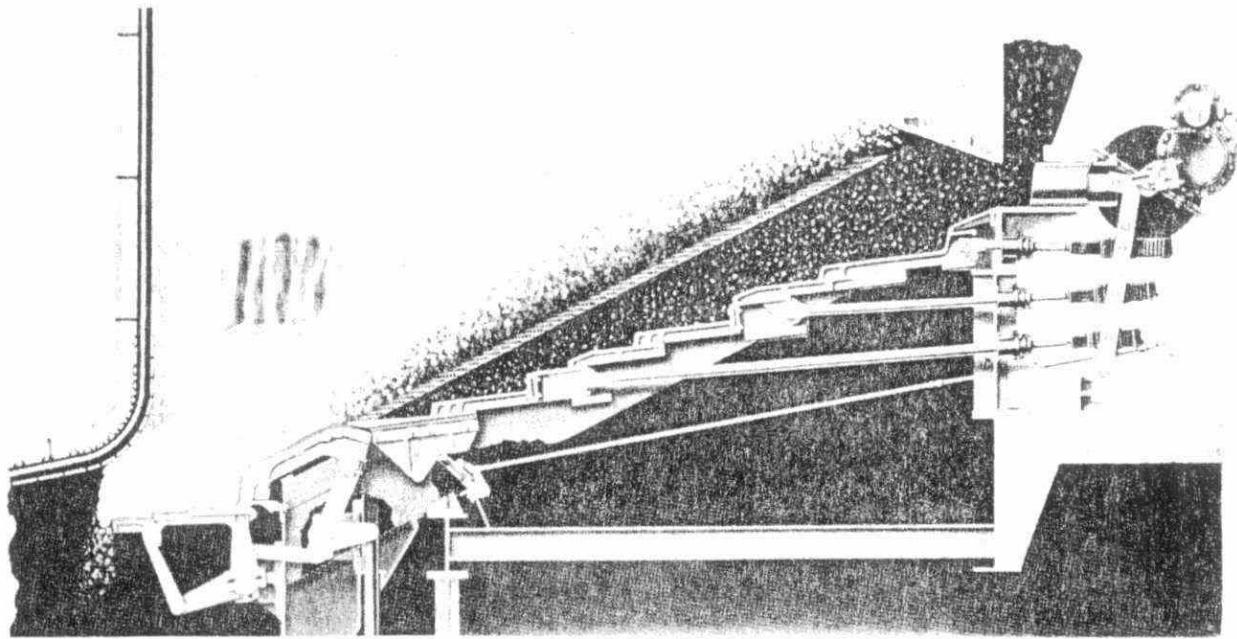
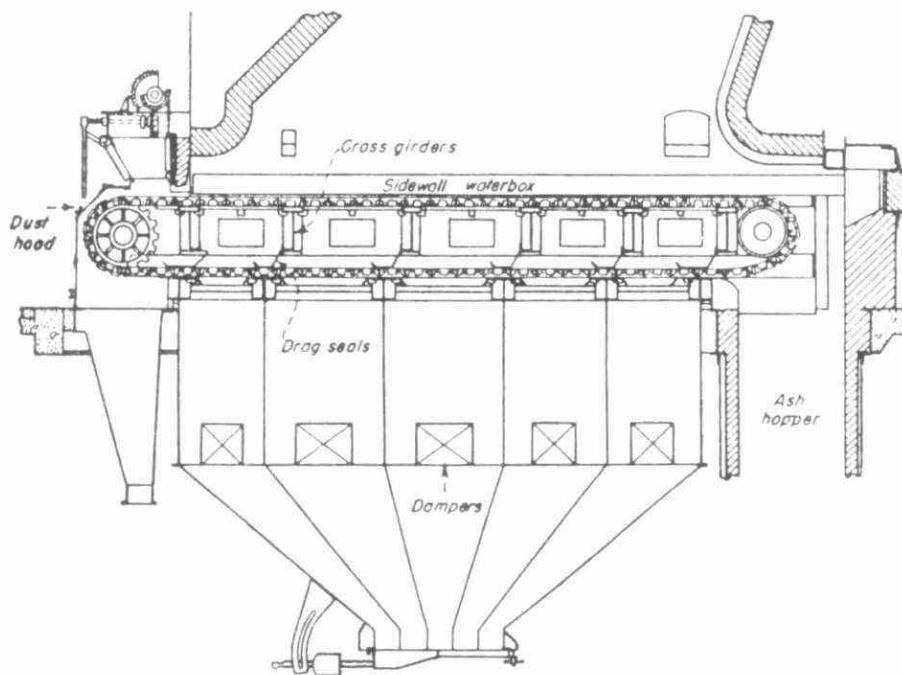


FIGURE 6-3

Multiple Retort
Underfeed stoker - ram type

CHAIN GRATE: BOTTOM AIR DISTRIBUTION



Chain-grate stoker with bottom air distribution: dampers in individual compartments regulate air flow to each grate section from front to rear

FIGURE 6-4

by linkage. When set properly, the stoker will rarely reach the off cycle, and, if it should, the stoker will always stop in the low position and start on the low feed low air cycle.

The results show greater uniformity in fuel bed thickness, improved combustion, cleaner operation and increased efficiency.

Similar to the screw feed type the principle of the ram type is to force the coal up through a retort and through the various zones in the fuel bed for complete burning of the volatiles.

The coal is fed into a hopper and is moved into a deep rectangular retort below the burning zone by a mechanically driven ram or plunger. With some of the ram type single retort and multiple retort stokers, pusher blocks are connected on a rod to the ram in order to provide proper distribution of the coal. Some of these stokers are also equipped with moving grates which assist further in proper distribution, and prevent the matting and caking of the fuel on the grates. Generally, as the fuel cokes and then burns the ash moves to the dumping grates at the side of the furnace. The dumping grates are periodically dropped and ash deposited into the ash pit.

Where only dead plates are provided, ash is removed by hand. Air supply is produced by a fan that operates as an integral part of the fuel feed, and with "off" and "on" operation there is a deficiency of air supply to the fuel bed when boiler demand is met and the fan shuts down. There are several types of fuel feeding stokers, but with the exception of small differences they are essentially the same.

Underfeed stokers should avoid heavy overloads, especially on the longer ram type, as with the heavier fuel bed that is the result of the extra load the coal characteristics may change, clinker is formed, and then we have trouble with smoke. When overloads are to be maintained, consideration should be given to a higher grade of fuel that is free burning, of uniform size and has a higher Btu value.

High volatile content in the coal and cold furnaces, such as might be the result of a water-cooled surface being too close to the fuel bed, tend to increase the hazard of smoke. Overfire air has sometimes been used successfully as a corrective measure where smoke problems exist. In general, the underfeed stoker is reasonable free from fly-ash carry over problems, but heavy coking of the coal creating fissures in the fuel bed and resulting in high local air velocities can create such a problem.

Coal should never be hand fired on a stoker as the principle of combustion in hand firing is quite different. The stoker control should be allowed to follow load swings.

Cleaning Stoker Fires

6.6 Cleaning stoker fires requires considerable care. When the fuel bed has increased beyond its normal depth, due to ash and clinker accumulation, the coal feed should either be reduced or shut off for 10 to 20 minutes before the fire is to be cleaned. This will permit easier cleaning. Use the slice bar, or poker, to lift clinkers from the dead plate and move to a position against the boiler water let or firebox side walls. Start the stoker while permitting the clinker to remain in this position for 15 to 20 minutes for cooling

before removal. This minimizes objectionable odours and fly-particles being released from the clinker, which would occur if they were removed from the furnace in an extremely hot condition.

Do not use hoe to clean fires.

Do not slice or probe over retort area, this will cause large clinkers and damage to stoker iron.

Do not remove loose ash from firebox.

Rebuild fuel bed to a depth of 10" to 14" over the centre of the retort. Re-adjust the forced draught fan damper as required, to stabilize the fuel bed at this depth, while still maintaining smokeless operation.

For maximum performance and minimum smoke emission, one side of the stoker should be cleaned at a time, waiting at least 30 minutes before cleaning the other side.

Do not shovel coal on the fire. Adjust the coal feed rate to build up the fuel bed.

Starting Fire on Underfeed Stokers

- 6.7 Remove clinkers from firebox and retort.
 Ensure that tuyere air slots are clear.
 Leave loose ash on dead plates to a depth of 1"
 or more.
 Run stoker until fresh coal in retort is level with
 top of tuyeres. Close forced air draught
 fan manual damper.

Place kindling on scrap paper base on top of coal in retort. Ignite paper. Open fire door vents and adjust stack damper for sufficient furnace draught.

When kindling burns brightly start stoker.

As coal ignites and fuel bed increases in depth, gradually open forced draught fan damper until combustion air is sufficient to maintain bright yellow flame.

Adjust coal feed to maintain the fuel bed depth.

Adjust hand operated stack damper for 0.05 to 0.10 inches w.g. (over the fire) measured while stoker is running. If draught control system is used, place on automatic control.

Build fuel bed depth to 10" to 14" over centre of retort, re-adjust forced draught fan damper as required to maintain this depth without smoke, re-adjust furnace draught as necessary.

When stoker burning rate satisfies initial boiler load, set coal feed rate for continuing load and adjust forced draught to maintain good combustion and proper fuel bed depth.

6.8 Operating Problems - Screw Feed

<u>Symptoms</u>	<u>Cause</u>
Hopper Gas	Excessively dirty fuel bed. Clinker in retort. Coking in retort. Hopper smoke pipe plugged up. Smoke back by-pass clogged. Worn screw.
Smoke	Fuel bed too thick. Not enough air. Poor draught. Insufficient slack in coal. Insufficient overfire air.

Fly-ash	Fuel bed too thin. Too much forced air. Excessive draught. Heavy coking causing fissures.
Soot	Fuel bed too thick (sluggish fire). Air supply rate too low. Insufficient overfire air.

6.9 Operating Problems - Ram Type

<u>Symptoms</u>	<u>Cause</u>
Uneven burning of coal over retort	Clinker in retort, or plugged tuyere openings. Inconsistent or disproportionate fuel sizing. Accumulation of grate siftings in windbox. Unequal coal distribution.
Coal does not burn as fast as stoker needs	Lack of ventilation air to forced draught fan. Lack of windbox pressure caused by malfunctioning dampers. Lack of windbox pressure caused by excessive leakage in the stoker setting (windbox, air-tubes, dead plates, etc.). Dirty fan impellers or air tube obstruction. Insufficient furnace draught.
Hopper gas	Excessively dirty fuel bed. Clinker or coking in retort. Insufficient slack in coal. Fire burning low in retort.
Chimney Smoke	Fuel bed too thick. Insufficient underfire air or overfire air. Insufficient slack in coal.
Fly-ash	Fuel bed too thin, or fissures in fuel bed. Too much underfire air. Excessive furnace draught.
Soot	Fuel bed too thick (sluggish fire). Insufficient underfire air or overfire air.

3. Chain-grate Stokers (Figure 6-4)

6.10 The chain-grate stoker consists of an interlocking endless chain of short staggered links, which travels slowly from the front of the furnace to the back, around sprocket wheels whose teeth mesh in the bottom of the links and drive the chain. The endless chain revolves round the length of the stoker chassis. Coal is fed by gravity from the hopper which supplies coal the whole width of the grate, first passing under a feed gate which controls the depth of the fuel bed.

The coal is ignited by the heat reflected on it by the coking arch which extends over the entire width near the front of the grate. The coal is carried forward slowly until at the end of the chassis combustion has been completed, the ash drops into the ashpit, and the grate continues back underneath the chassis to be re-fed continuously with fresh coal.

The drive is continuous and variable being actuated by gears enclosed in an oil case. On average load the grate surface moves at about 6" per minute. Air for combustion is admitted between the grate links and can be zoned by dampers.

A similar type of stoker is called the travelling grate stoker (Figure 6-5). It differs in structural design from the chain-grate stoker, but functionally it is the same. It has a drive chain at each side with cross-bars at intervals. The long clips that form the grate surface are attached to these cross-bars, and overlap to prevent ash sifting through. Chain grates were originally developed for bituminous coal, and travelling grates for small sizes of anthracite.

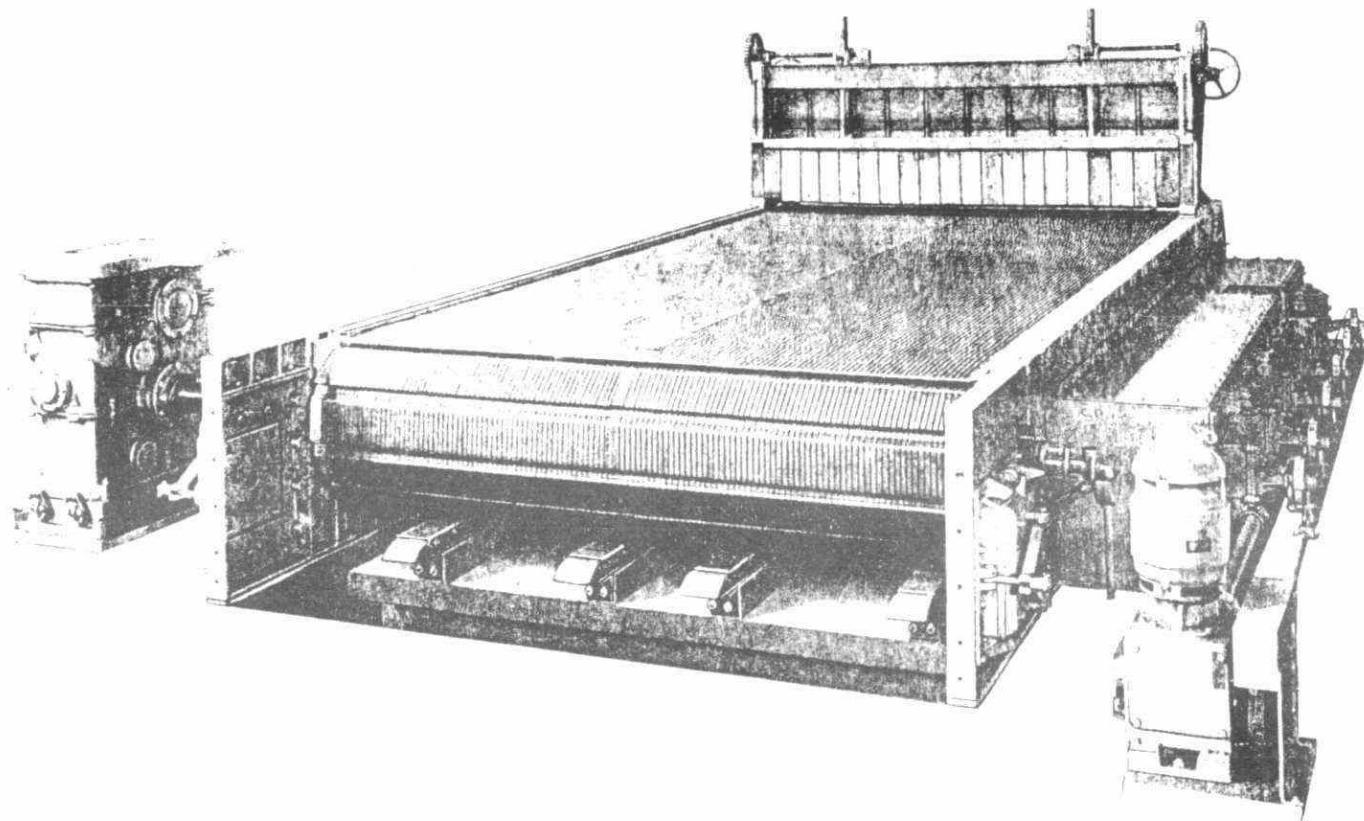


Figure 6-5 Travelling Grate Stoker

The fuel in chain-grate stokers is not disturbed or agitated, which reduces the clinkering and fusion of the ash. Wet coal is not a problem with this stoker, and with coals of very low moisture content, it may be necessary to wet it, so as to give uniform and even burning across the fuel area. The design provides for air flow to different zones, and for best results air distribution must be adjusted and maintained at the correct flow. Overfire turbulence must be thorough, and if it is not adequate, installation of overfire jets may help improve faulty firing. When burning fine coals, the fire should be thin and the grate sent along at a higher speed to give the desired combustion rate. These stokers are mounted so that the whole unit can be run out from the boiler setting.

SUBJECT:

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

TOPIC: 7

SUSPENSION FIRING

OBJECTIVES:

The trainee will be able to:

1. Explain briefly how pulverized fuel is burned as a fuel;
2. State the conditions necessary to achieve complete combustion of fuel oil;
3. Describe the functions of an oil burner;
4. Explain why draught diverters are fitted in atmospheric gas burner installations.
5. State the advantages of the industrial power burner (gas) over atmospheric type gas burner;
6. Describe a barometric damper and explain its function.

SUSPENSION FIRING

Coal (pulverized fuel - P.F.) (Figure 7-1)

7.1 In this system, coal is burned under conditions that allow the fuel to mix intimately with combustion air giving practically instantaneous ignition and complete combustion. It is fired as a finely powdered fuel that is injected into the furnace in a manner not unlike that used for fluid fuels. This is achieved by pulverizing the coal to a fineness of 70% or more through a 200 mesh sieve and at least 98% through 50 mesh. It is then transported by hot primary air, which also dries the coal, to the furnace. By this method, coals can be utilized that would be impossible to burn on a grate, and it has great flexibility of operation, approaching that of oil or gas. The majority of all central steam generators operating at 200,000 lb. steam/hour and over are fired by pulverized coal.

7.2 The two basic pulverizing systems are:

1. The "bin" system
2. The unit or direct-fired system

The older bin system has now been largely replaced by the unit system which is used almost universally in new plants.

In the bin system, coal was dried, pulverized and stored to await demand. Storage reduced need for spare pulverizer capacity and burners could be controlled separately with ease.

In the unit system, pulverizers feed burners directly. There is no storage, operation fluctuating with steam demand. It involves less equipment, short lengths of piping to the burners, and avoids storage-bin

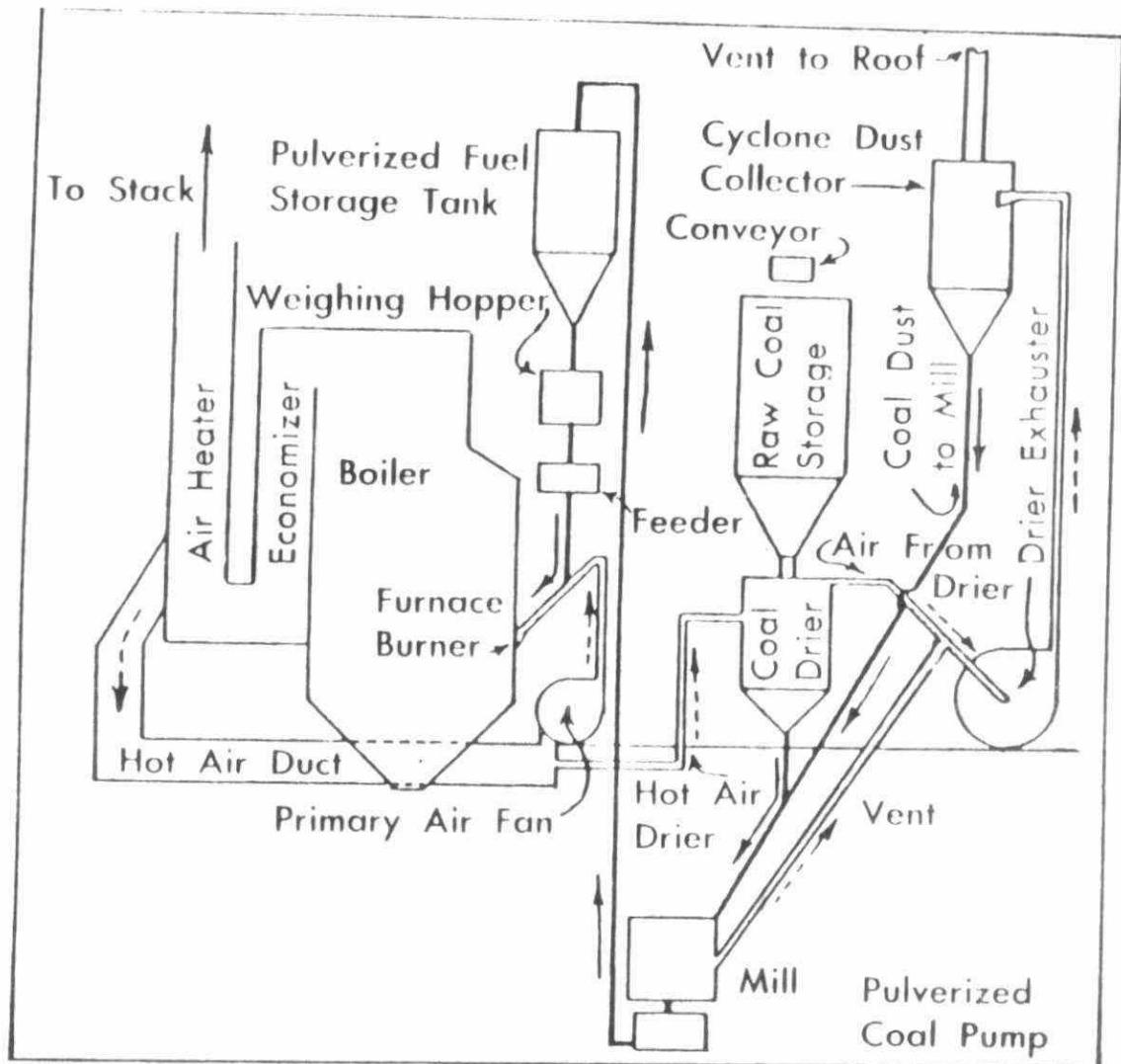


Figure 7-1

SCHEMATIC DRAWING OF SUPPLY SYSTEM FOR
PULVERIZED FUEL SYSTEM

fire hazard. It has the flexibility needed to handle various functions under a wide range of load and coal conditions.

7.3 Pulverizer designs are numerous but they employ three basic forces singly or in combination: 1. impact 2. attrition, and 3. crushing. The ball-mill resembles a tumbling barrel with its rotating drum filled with coal and many heavy steel balls. In other types, pulverization is achieved between balls and grinding rings; between a whirling bowl and rollers; by whirling hammers and pegs; and by converging jets of steam or compressed air at the area where the coal enters.

7.4 Uniform fineness of the fuel assists greatly in increasing efficiency, and uniform size is more important than fineness. No matter what the percentage of coal that will pass 200 mesh, as little as 5% over the 50 mesh limit may result in slagging and increased combustible loss.

7.5 Pulverized coal boilers may employ vertical, horizontal, opposed, or tangential firing methods. All of these methods are designed to promote turbulence. The latest tangential firing installations employ fully automatic control of burner inclination, by which the flame zone is adjusted vertically, so regulating temperature of exit gas according to load. This, in turn, controls superheat over a wide load range.

7.6 The burner may be any shape but basically the primary air carrying the fuel passes through the centre of the burner and the casing surrounding the burner is provided with dampers for secondary air. The air enters at fairly low velocity and arrangements must be made to prevent back firing. Primary air for pulverized fuel is limited by the mills and burners, but it is usually held to approximately 107°C , depending upon the moisture content of the coal. Usually, an auxiliary oil

or gas burner, electrically ignited, is employed for ignition.

7.7 A disadvantage of pulverized fuel is in the quantity of fly-ash which, if not collected, is discharged into the atmosphere. Depending on the type of furnace, anything from 40% to 90% of the total fired ash leaves with the combustion gases. With 15% to 22% excess air, the unburned combustible is under 1%. The excess air requirements will vary from 10% to 30%; as the percentage of ash increases the amount of excess air must also increase, if the combustible loss is to be held to a constant minimum. Grit and dust from these units is usually collected by means of multicyclones and electrostatic precipitators.

7.8 Although it was mentioned earlier that primary air is usually held to approximately 107°C, depending upon the moisture content of the coal, this may be as low as 65°C, for some coals, and to ensure stability of ignition should not be less than 52°C. Secondary air temperatures may range as high as 370°C. Typical efficiencies of large units with air heater and economizer may range from 87% to 89%.

Oil

7.9 Complete combustion of liquid fuel oils depends upon their complete vaporization since oil does not burn in its liquid state. When vaporization has been effected, then adequate mixing with oxygen in the air and a sufficient length of time at a sufficiently high temperature are required to complete the oxidation of the hydrocarbon molecules, and to derive all the heat available from this reaction.

7.10 The wide variety of liquid fuels and the wide varieties of burners available to utilize them, make it necessary to have an intelligent match of fuel oil and combustion equipment. Burners and furnaces are designed to handle specific fuels in specific quantities. Attempts to use a lower grade of fuel than anticipated by the equipment designer, or to use the recommended grade in quantities which are greatly in excess of those intended, will inevitably lead to difficulties in completing combustion. Similarly, far too little oil burned in a large furnace will also cause trouble. While the variety of mechanical difficulties are innumerable, they can all be traced to some shortcoming in the time, temperature and turbulence required to complete combustion. Many of these points were elaborated on under "Combustion" and "Fuels". Common causes of poor combustion are shown in Table 7-1.

7.11 An oil burning system consists of storage tanks, oil pumps, oil heaters, oil burners, strainers, pipelines, valves, measuring instruments, and control equipment. The oil heaters may be heated by steam, hot water, or electricity. The oil temperature required at the entrance to the burner to give a suitable viscosity for atomization is usually between 65° and 93°C, unless the oil is of a low viscosity and does not require pre-heating, and steam supplied to the jets ranges from 25 to 80 lb. psig. Some types have hand lighting and others are automatic.

7.12 A requisite for any combustion system is a proper arrangement for supplying the necessary amount of air for combustion, without upsetting the atmospheric pressure balance in the boiler room. To give some idea of the air quantities we are talking about, to achieve perfect combustion of 1 gallon of #2 oil would require 1,140 cu. ft. of air. In actual practice, since all burners

Table 7-1

Common Causes of Poor Combustion in Boilers

<u>Cause</u>	A	B	C
1. Insufficient air or too much oil.	A	B	C
2. Poor draught.	A	BB	C
3. Excess air (causing white smoke).	A		
4. Dirty or carbonized burner tip.	A	B	
5. Carbonized or damaged atomizing cup, (rotary).	A	B	
6. Worn or damaged orifice hole.	A	B	
7. Improper burner adjustment.	A	B	CC
8. Oil pressure to burner, too high or low.	A	B	
9. Oil viscosity too high.	A	BB	
10. Oil viscosity too low, - too high fuel oil temp.	B	C	
11. Burner is being forced.	A	B	C
12. Insufficient atomizing steam.	A	B	C
13. Water in fuel oil.	A	B	C
14. Dirty fuel oil.	A	B	C
15. Fluctuating oil pressure.	AA		
16. Incorrect furnace construction causing flame and oil impingement.	A	B	
17. Carbon clinker on furnace floor or walls.	A	B	
18. Incorrect atomizer tip size.	A	B	
19. Condensate in atomizing steam.	A		C
20. Atomizing steam pressure too high.			C
21. Furnace cone angle too wide.	A		C
22. Furnace cone angle too narrow.	A	B	C

A = Smoking fire

AA = Intermittent

B = Carbon formation

BB = Sometimes

C = Fire pulsates

CC = Sometimes

require excess air for combustion, the amount of air required for 1 gal. of #2 oil is more like 1,500 cu. ft. of air.

Burners

7.13 Essentially, an oil burner is a fuel converter, that is it converts fuel into usable heat. It does this by breaking up the liquid oil into small particles, combining these small particles with air, igniting this mixture and continuing the burning process. To do these things automatically, a burner needs first atomizing components; second, air handling components; third, ignition components; and fourth, a suitable combustion chamber.

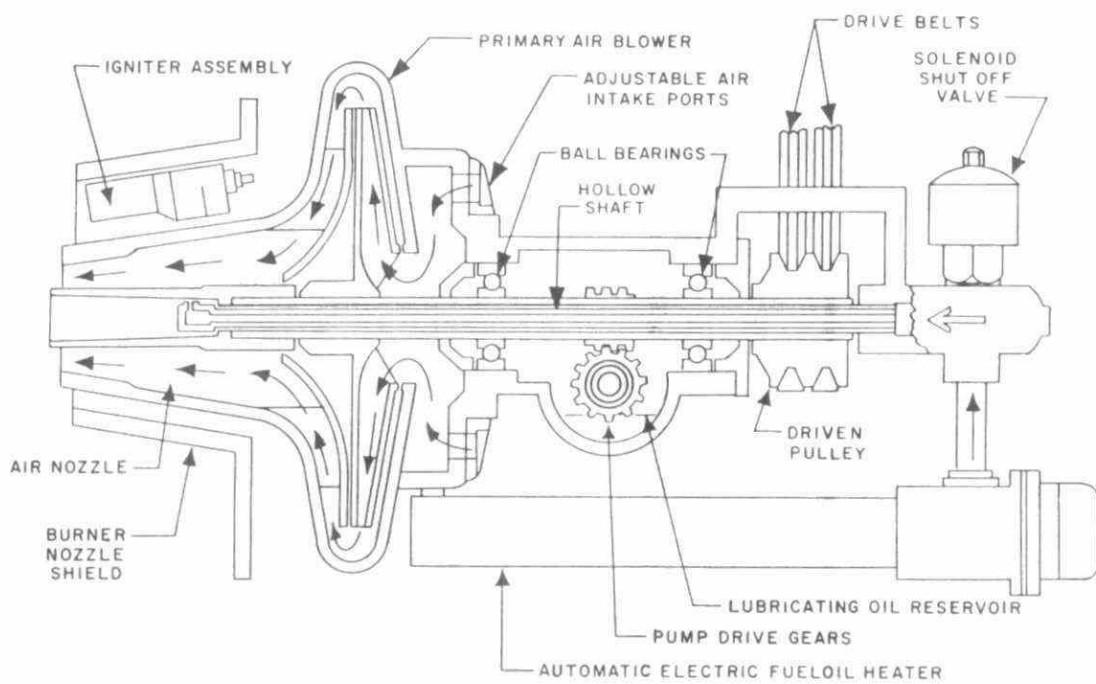
7.14 In general, an efficient oil burner must serve four primary functions:

1. maintain uniform atomization over a comparatively wide capacity range;
2. thoroughly atomize the liquid fuel oil into such fine particles that the combustion air can achieve the necessary mixture so quickly that it can be completely burned before any portion cracks thermally;
3. operate without impingement of unburned oil on the furnace walls; and
4. accomplish the mixture of air and oil throughout the entire firing range with a minimum of excess air.

Oil burners are available in a number of different types.

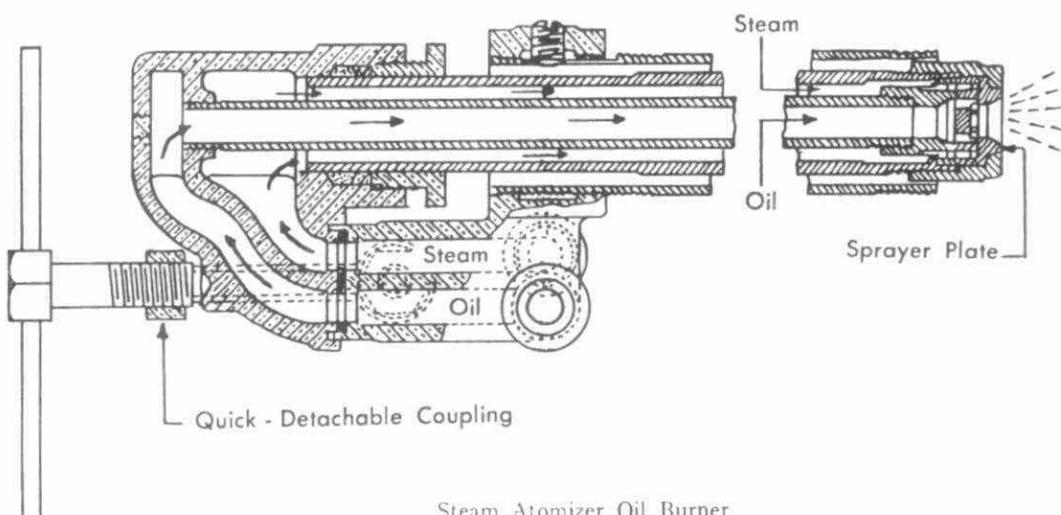
Rotary Cup Burner (Figure 7-2)

7.15 This is one of the earliest oil firing burners for large gallonage and still is. They are capable of



Oil and Air Handling Parts of Rotary Burner. Motor is located above this assembly.
Arrows show primary-air flow.

FIGURE 7-2



Steam Atomizer Oil Burner.

FIGURE 7-3

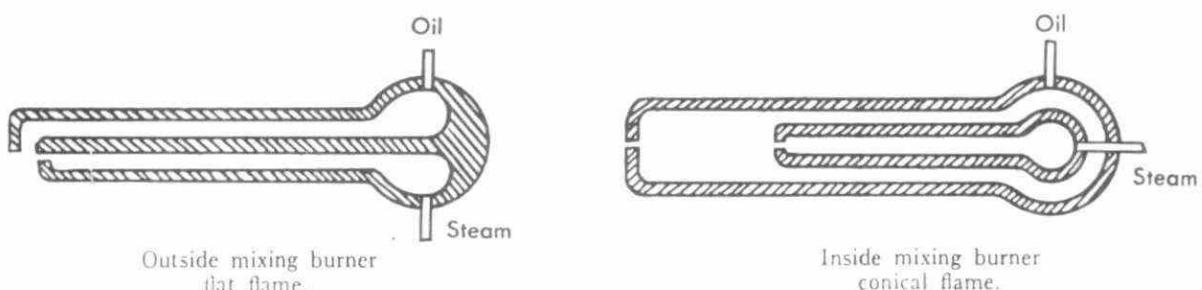


FIGURE 7-3A

firing virtually all grades of oil from #2, to Bunker C, and range in size up to 300 gallons per hour.

The main characteristic of these burners is the high speed atomizing cup which rotates from 3,500 r.p.m. and up. The cup is tapered with the large end facing the combustion zone. Fuel is deposited on its inner surface and the combination of centrifugal force and tapered construction flings the oil off the end of the cup in an extremely thin film. The shape and machining of this cup is very critical. Any abrasion, distortion or gummy deposits can seriously affects its oil delivery characteristics; on the other hand, given proper care, it is a very stable atomizer and has a long life.

Another characteristic of the rotary burner is the radial type primary air fan, which turns at the same speed as the atomizing cup and delivers air through a shaped nozzle from around the periphery of the atomizing cup. Both the air nozzle and the atomizing cup must be matched for proper results.

In what is known as a straight rotary, or more accurately a simple rotary burner, the only two functions served by the burner are to atomize oil and to supply primary air. Since primary air accounts for only about 15% of the total air required a separate source is required for secondary air. A common method of introducing secondary air to simple rotary cup burner installations is through open squares in the combustion chamber floor with air feeding from beneath it.

Another variety of rotary cup burner employs an air register for supplying and controlling secondary air without the requirement of a checkerboard combustion chamber floor. In this case, secondary air flows through an orifice ring of refractory tile which surrounds the spinning cone of oil film. A wider range of firing rates can be accommodated with this arrangement.

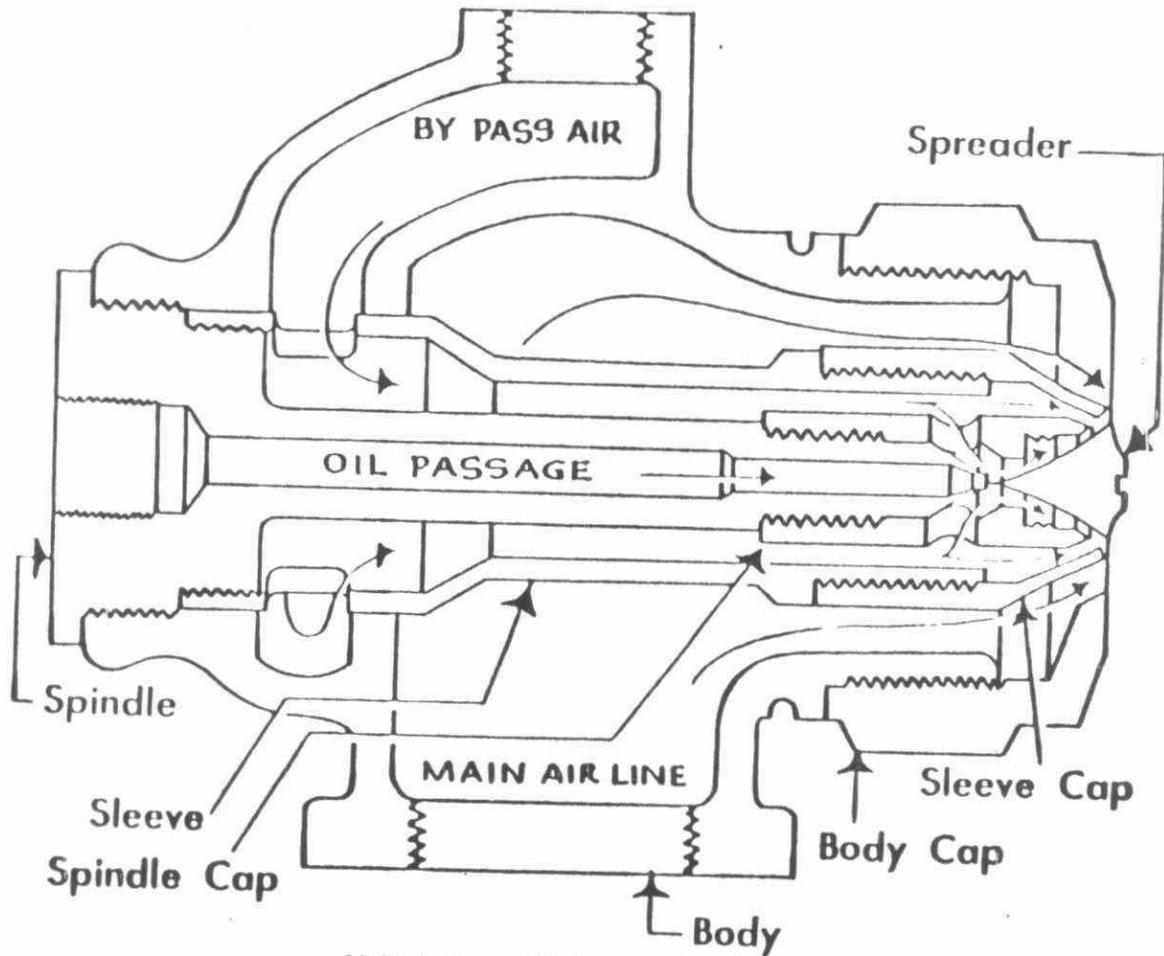
Another type is the forced draught version. With this equipment secondary air is forced through an orifice ring under pressure and under very precise control. This is the modern rotary cup unit with complete mechanical control over both primary and secondary air.

The rotary cup is no longer considered good design practice and is not recommended for new installations.

Steam Atomizing Burners (Figure 7-3)

7.16 Steam atomizing burners can be divided into the inside mixing and the outside mixing types of burners which are illustrated in Figure 7-3A. In the outside mixing burner, the steam and oil are mixed externally at the burner tip producing a flat flame. It is limited in application to boilers requiring moderate burning rates with relatively little variation in loading. The inside mixing burner atomizes the oil internally. Some designs of this burner produce a flat flame, and others a conical flame controlled by air registers. The air for this latter type of burner is induced both by the furnace suction and the aspiration of the expanding steam jet in the burner nozzle. Generally speaking, as the firing rate increases the pressure of the oil goes up and the steam pressure also rises. At the nozzle itself, the two pressures remain about equal.

As in the case of rotary cup burners, steam atomizing equipment employs different means of controlling secondary air; this is largely a matter of manufacturer's design and preference. It can range from quite simple arrangements to a highly sophisticated fan driven, damper controlled diffuser head arrangement, such as is found on the newest units.



Multiple Spray Oil Burner Using Low Pressure Air.

Figure 7-4

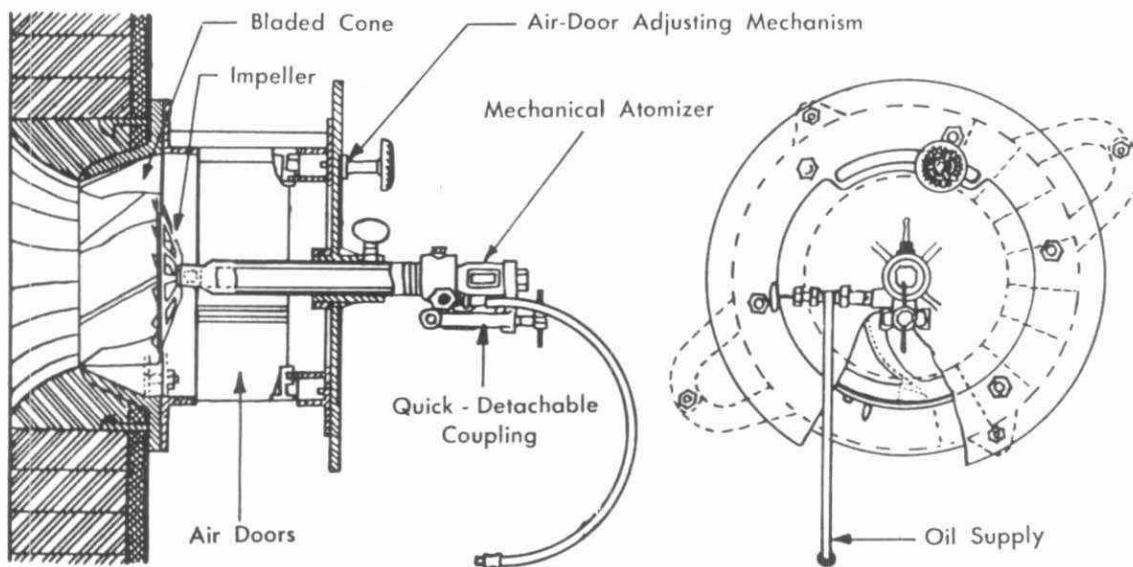


FIG. 50. Mechanical Atomizing Oil Burner fitted in Boiler Front.

Figure 7-5

Air Atomizing Burners (Figure 7-4)

7.17 The atomizing primary air from the air compressor is supplied to the nozzle through the primary air tube. Oil flows through the oil tube which runs down through the centre of the air tube. The primary air is supplied to the nozzle at approximately 15 to 20 psig; the fuel oil at about 10 to 15 psig. The primary air is delivered at about 93°C, and gives the oil passing through the oil tube a final shot of heat before atomization. This air during the 30 second pre-purge period before the oil valve opens quickly, brings the oil tube up to temperature.

The atomizing air and the fuel oil being fed to the nozzle by separate channels meet in tangential slots cut into the conical face of the core. An oil passage is located at the centre of each slot. The size of the oil holes are such that the oil oozes out under very low velocity whereas the slots are sized to carry the air at a high velocity. The air stream, in effect, wipes away the oil oozing out and charges into the internal mixing chamber within the tip of the burner. Here the oil and air is churned and emulsified before being discharged into the furnace in the form of a fine fog-like atomization of an air-oil emulsion.

The internal mixing of the primary air and the oil provides an extremely fine and intimate air-oil mixture which ignites and burns quickly and cleanly. Since the secondary air from the forced draught fan is not needed for atomization purposes, it is introduced under low velocity to shape the flame and ensure complete combustion with a minimum of excess air.

The secondary combustion air amounts to about 98% of the total air required to provide complete combustion. Since the combustion air has no atomizing function and is

introduced with a low velocity, it can be readily turned down in the same ratio as the fuel without impairing atomization or combustion while maintaining a relatively constant percentage of excess air.

Mechanical Atomizing Burners (Figure 7-5)

7.18 The domestic version of this type of burner is the popular pressure atomizing or gun-type burner. Here an electric motor drives a fuel unit that discharges fuel through an atomizing nozzle into the combustion zone and at the same time drives a small fan which supplies air to the oil spray at the same point. A high voltage spark supplied by a transformer to two electrodes ignites this air-oil mixture, and the resulting products of combustion are in turn drawn through the furnace area by natural draught created by a chimney.

The term "pressure atomizing" refers to the fact that oil is broken up by oil pressure, and the atomizing nozzle. Another version of this type of burner employs an induced draught fan on the discharge side of the unit, which controls the total flow of air handled by the burner without the assistance of natural draught. This results in a fully mechanical control of the air-oil mixture.

The industrial version of this type is designed for medium and heavy oil, that usually must be pre-heated to very closely controlled temperatures.

The principle of atomization is the same as employed with the conventional domestic gun-burner, except that oil pressures are much higher.

Natural Gas

7.19 From the combustion point of view, natural gas is the ideal fuel. It is pure and it comes in the form to which all fuels must be converted prior to combustion. It is the simplest of all fuels to burn and the cleanest. Solid particulate pollutants are only produced from the combustion of natural gas in one situation, when combustion air supply is restricted and carbon black or soot is produced as a dense black smoke, but, generally, any problems arising with its combustion are readily remedied.

Gas Burners

7.20 The gas burner is a device that combines the gas and air into a mixture which can ignite safely from one source of ignition, thereby producing flame and liberating heat energy.

Gas burners are classified both as to their usage and by the principle used in combining the fuel with air. In the first case they are called domestic units, commercial units and industrial units. In the second case they are known as atmospheric and power burners. Power burners are sometimes also referred to as forced draught burners.

A gas burner in its simplest form can be a gas pipe that has been lit. In its most refined form, a burner becomes a fairly complex combination of regulators, valves, orifices, controls, electrical, and safety devices.

The main characteristic of the gas burner is that it uses a fuel supplied under pressure and ready for burning. The fuel has only to be mixed with oxygen and ignited to obtain combustion. This is not the case in solid fuel burning devices, or oil burning devices.

All of these fuels have to change their state by either mechanical or chemical means before combustion can be achieved.

Domestic Atmospheric Mixing Burner (Figure 7-6)

7.21 This is the most common type of burner and is found in heating boilers and furnaces. It uses what is called the injector principle. The fuel, under pressure from the distribution lines, is discharged through a fixed orifice into a throat of a venturi tube. This combination causes air to be induced into the venturi tube through a primary air shutter where it mixes with the gaseous fuel. This mixture then travels through the tube to the burner head where it is ignited and burned.

The secondary air for combustion enters the combustion zone from around the outside of the venturi tube, and is controlled either by a moveable damper, or by a fixed restrictor in the flue passes of the heat exchanger.

This same principle of atmospheric mixing is found in the standard gas cooking stove, domestic water heaters, furnaces, conversion burners, as well as in commercial and industrial burners.

Another thing all atmospheric gas burners have in common is the draught diverter, sometimes called a draught hood. In typical conversion jobs the diverter, or hood, is installed in the flue or vent. In many gas designed appliances the diverter is made an integral part of the unit. In either case, the draught diverter serves three essential functions:

1. Governs the amount of draught over the fire by neutralizing the pull of flue or vent

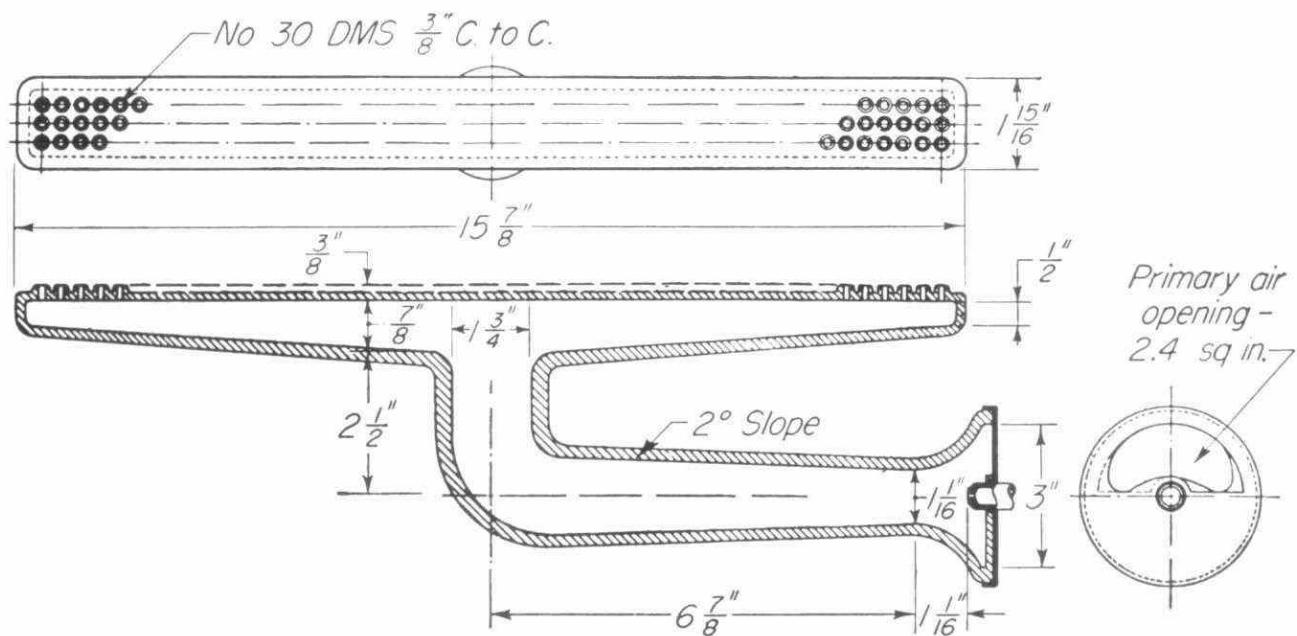


Fig. 7-6 Domestic Atmospheric Mixing Burner

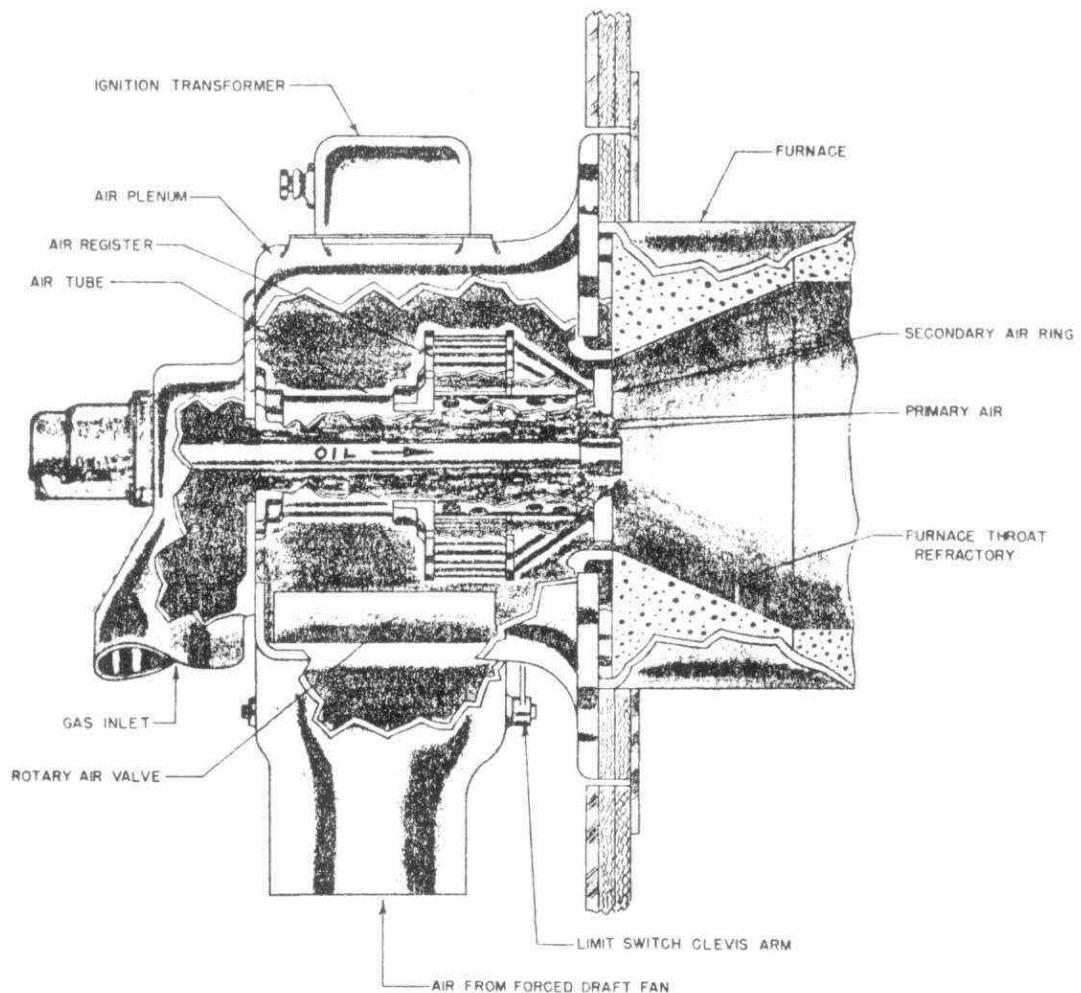


Fig. 7-7 Model 3 Combination Gas - Oil Burner Assembly

2. Prevents back draught from entering the combustion zone.
3. Ensures the ready escape of the products of combustion in the event of no back draught, or a stoppage in the vent or chimney.

The draught diverter is an important operating and safety feature, and when installed as part of the vent, must exactly follow manufacturers' recommendations and applicable codes. Improperly sized or installed draught diverters can result in the presence of lethal carbon monoxide; inability to achieve rated input; nuisance shutdown; and inefficient, uneconomical burner operation.

Essentially, a draught diverter handles air, so we see once again the important role played in air combustion systems by proper handling.

Commercial Atmospheric Mixing Burner

7.22 The atmospheric burner in the commercial application can be further classified in two ways:

1. A vertical venturi burner
2. A horizontal venturi burner

The vertical venturi style of burner is usually constructed of cast-iron with square or rectangular burner heads sitting atop a venturi tube. These heads have raised, drilled ports, and the venturi throats are fed from a manifold containing the gas jets. The burner heads are located at grate level within a boiler, and can be arranged in rows of varying lengths and/or widths to fit the shape

of the boiler in which they are installed. The output per burner head varies with manufacturers, but, generally speaking, are designed to accommodate boilers with 8 to 10 sq. ft. of heating surface per boiler h.p.

When less than the entire grate area is required for the proper number of burners, the remainder of the grate area is covered over, so that secondary air will be controlled and directed to the burner area only. The burner base or draught box is sealed tightly to the boiler, ensuring that all combustion air requirements are controlled by passing through a damper. This type of burner does not require a combustion chamber, since the burner heads replace what was once the coal bed and the flame is entirely surrounded by water backed surfaces.

The horizontal venturi style of burner has the venturi tubes fixed in the horizontal plane. The venturi tubes together with secondary air tubes are embedded in refractory giving a honeycomb appearance. A windbox and air control dampers are located on the outside of the boiler. Since this style of burner is located in the base of the boiler, a combustion chamber extending up to slightly above the water leg is required, the number and firing rate and arrangement of the venturi is variable.

Industrial Power Burner (FIGURE 7-7)

7.23 In the true power burner, all air for combustion is supplied under pressure by a single fan, and the burner can operate without the assistance of natural draught. In addition, these burners usually can operate against furnace back pressure, and because of this capability can be made a part of a packaged boiler burner unit with very high efficiency.

The mixing of the fuel and air takes place under pressure from the fan through a high resistance firing head, producing a short, clean, stable flame, free of pulsation and using a minimum of excess air. Very precise control of the air-fuel ratio is maintained, and fuel inputs can be modulated through a fairly wide range. Freedom of these burners from a natural draught requirement eliminates any of the deficiencies of the atmospheric type burners which are caused by erratic, or excessive, overfire draught conditions. Since the burners are a complete combustion system, they can be applied directly on the combustion zone on a boiler, and a combustion chamber, therefore, is not necessary.

The forced draught power type gas burner represents the greatest advance in the proper handling of combustion air, and is, therefore, the ultimate in the burning of gaseous fuels.

The gas handling components that are part of all gas burners are prescribed by codes and standards set forth by several approving agencies. Every automatic gas appliance will have at least the following:

1. Regulation of gas pressure to the burner
2. A flame safety and ignition device
3. An automatic gas valve
4. A manual shut-off cock
5. A thermostat, or other automatic heat control.

In the larger commercial and industrial size burners a programme control system is employed to ensure through a definite timed sequence, a pre-purge of the boiler before ignition, a proof of ignition, a safety shutdown, and post-purge after the firing cycle has been completed.

Ventilation

7.24 Adequate ventilation of the boiler room is essential for proper combustion. Air for the boiler room may be brought in by natural or mechanical means. When exhaust systems are used any inlet air system must provide a greater volume of air than is required by the exhaust and stokers or burners. A totally enclosed boiler room with no opening to the outside air requires a mechanically induced inlet air system to satisfy stoker or burner requirements.

Barometric Dampers

7.25 A barometric damper may be necessary due to outside air conditions causing an unsteady flow in the stack and breeching. Before a barometric damper is installed, it should be determined that the instability cannot be corrected with the controls already available, i.e., boiler or breeching controls.

A barometric damper saves fuel by maintaining a steady draught in the furnace. The damper consists of a balanced metal disk mounted in the breeching between the boiler and chimney, and can be adjusted to furnish a steady draught in the furnace by means of the balance weight, the adjustment being made to achieve the lowest draught that will provide for proper combustion and remove the products of combustion, without too much excess air.

The area of the barometric damper should normally be equal in size to the area of the installed breeching:

1. If a chimney is less than 60 ft. high and a relatively high draught (0.15 - 0.20) is required, reduce the area of the barometric damper by 10%.

2. If a chimney is over 60 ft. high and a normal draught is required, (0.1 - 0.13) add 10% to the damper area for each additional 20 ft. of stack height.

If the required damper area is larger than the breeching area, this area may be achieved by the use of two or more dampers.

<u>Breeching Area Sq. Ins.</u>	<u>Diam. of Regulator</u>
113	12"
154	14"
201	16"
255	18"
314	20"
380	22"
452	24"

Care must be exercised when deciding where to locate a barometric damper. For boilers depending entirely on natural draught for supplying combustion air, the barometric damper should be located as close to the boiler as possible. For boilers depending on mechanical draught for supplying combustion air, the barometric damper should be located as far from the boiler as possible. The collar length of the barometric damper should be at least equal to the diameter of the breeching in order to keep the gate from swinging into the flowing flue gases in the breeching, and also to prevent the discharge of the flue gases into the surrounding area.

SUBJECT:

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

TOPIC: 8

AUTOMATIC COMBUSTION
CONTROL SYSTEMS

OBJECTIVES:

The trainee will be able to:

1. Explain the basic function of the automatic control system;
2. List the basic types of combustion control systems in increasing order of desirability, and briefly explain how each system works;
3. Explain why flame failure controls are necessary on automatic oil burner installations, and briefly describe how one effective type of flame failure control operates.

AUTOMATIC COMBUSTION CONTROL SYSTEMS

8.1 The function of the combustion control system is to adjust the rate of fuel feed to correspond to changing load requirements at all times, so that boiler pressures or temperatures are held within close limits. At the same time, the combustion controls adjust the combustion air supply to maintain the proper proportion of air and fuel required for clean, efficient combustion.

8.2 The basic types of combustion control systems in increasing order of desirability are:

1. "On-off" control.
2. Two stage "hi-lo" fixed position firing.
3. Full range modulation.

1. "On-off" Combustion Control

8.3 This form of control is aptly described by its name, the burner either fires at its maximum rating, or it is off. Its chief advantage is its simplicity, especially on smaller units where the cost of a modulating type of control cannot be justified.

2. "Hi-lo" Combustion Control

8.4 This system, as the name suggests, provides for two level burner operation. The high level is set at the maximum rating of the burner, while the low level is the burner's minimum firing rate. There are no intermediate firing points.

A burner with a "hi-lo" control system is ignited in the low firing stage. The burner is then brought to the high firing level where it is held until the boiler pressure or temperature actuated operating control is satisfied, whereupon the burner drops back to the low firing rate. If the load is less than the output afforded at the minimum firing rate, the burner will then shut down. Where the demand lies between the low and high fire rates, as is ordinarily the case, the controls will cause the burner to shuttle back and forth between the two firing levels. This action results in alternate periods of overfiring and underfiring the boiler. This type of operation also makes very difficult the maintenance of boiler pressure or temperature within close limits.

3. Full Range Modulating Controls

8.5 This is the true modulating system having no fixed or pre-determined firing positions. The controls provide an infinite number of positions between the maximum and minimum firing rates.

This combustion control system provides ignition in the minimum firing stage. The burner is then brought to the maximum firing rate until the boiler pressure or temperature to be maintained is reached, whereupon the firing controls will cause the burner to drop back to the exact firing rate to match the demand. The accuracy of these controls causes them to move to the exact position that properly adjusts the rate of combustion to match any change of load. The operation of these controls is shown diagrammatically in Figure 8-1.

OPERATION OF MODULATING CONTROLS

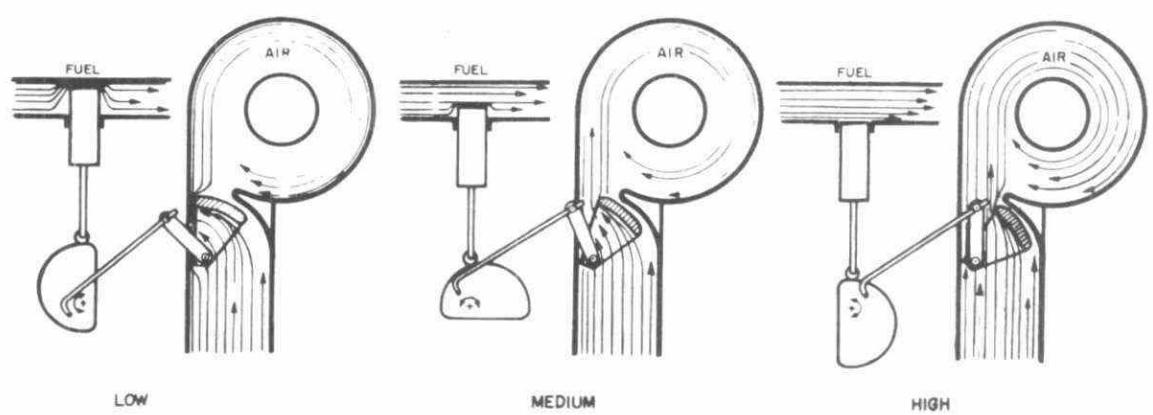


FIGURE 8-1

An auxiliary potentiometer type boiler pressure or temperature actuated switch mounted on the gauge panel with the limit switch, directly governs the operation of the infinitely variable modulating motor.

This auxiliary switch senses minute changes in boiler pressure or temperature, reflecting changes in demand, and sends a signal to the modulating motor which instantly compensates by adjusting the firing rate.

Multiple Fuel Control Systems

8.6 The function of any combustion control system is to maintain constant steam pressure by regulating the flow of fuel and air to the boiler in accordance with load demand. It must also control the fuel-air ratio in keeping with efficiency, economy and safety. Figure 8-2 illustrates the essential elements required to perform these functions. For simplicity hand/automatic selectors and other supplementary components have been omitted.

Steam pressure is measured and used as the initiating control signal because it is an accurate index of the relationship between load demand and heat release. By means of a pressure controller, it regulates both air flow and fuel flow to the furnace. As there is only one best relationship between fuel rate and the air supplied for any given set of conditions, these flow rates are measured and their ratio continually compared to that desired. The ratio controller then provides a re-adjusting signal to the master pressure controller outlet. The resulting signal from the averaging relay calls for sufficient fuel flow not only to satisfy load demand but to maintain optimum relationship between fuel and air.

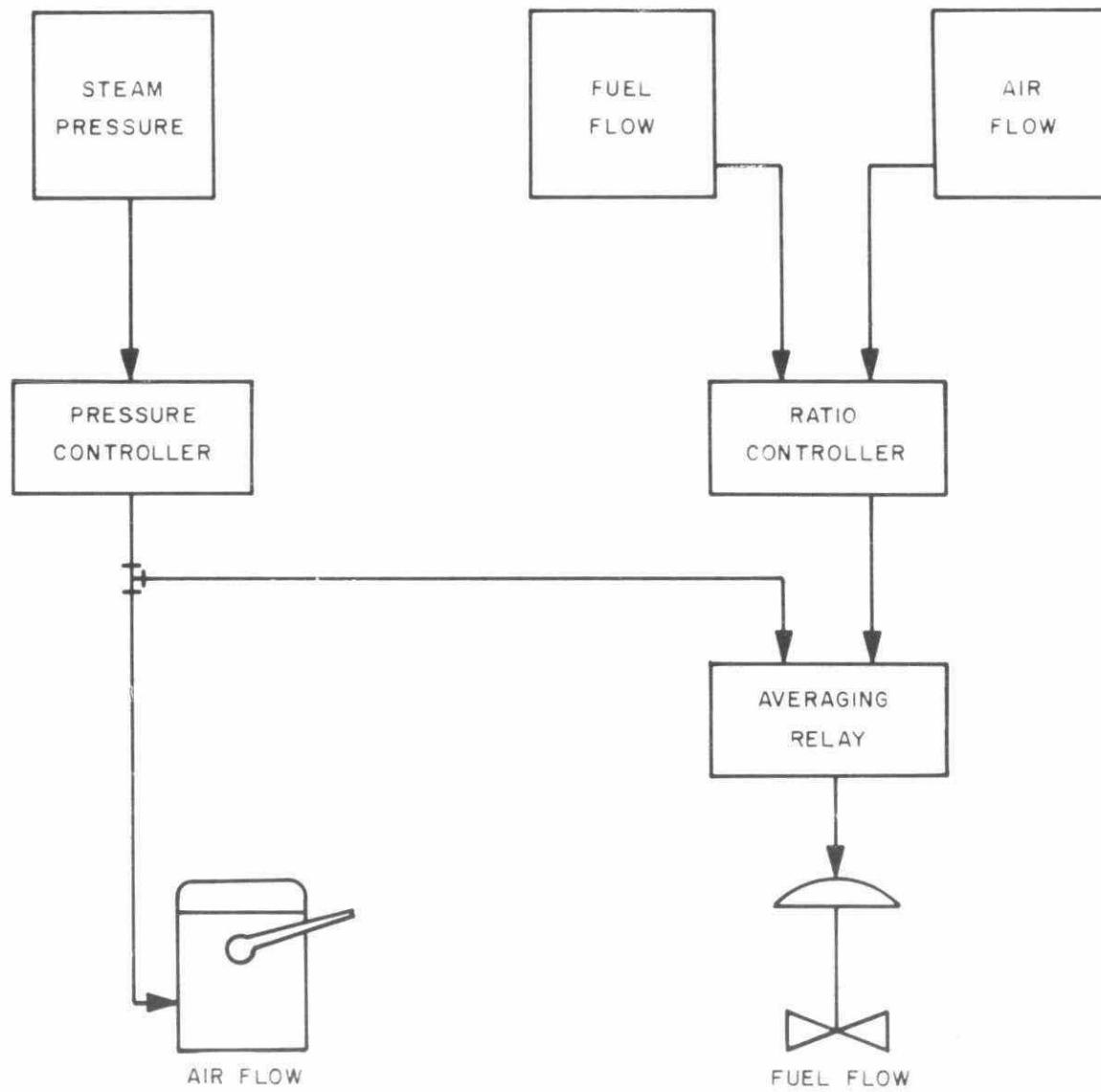


FIGURE 8-2 BASIC COMBUSTION CONTROL SYSTEM

8.7 When designing combustion control systems for multiple fuel boilers, modifications must be made to the above basic system depending on the combination of fuels and the manner in which they are to be burned. With each boiler, different control problems are encountered. Let us consider, for example, a boiler which is to burn oil and wood in combination. This situation is typical to that found in the Pulp and Paper industry.

The problems presented here are:

- 1) How to ratio fuel and air with two fuels, especially when one fuel is difficult to measure; and
- 2) How to obtain proper fuel/air ratio on automatic wood firing with varying moisture content.

Figure 8-3 illustrates one approach to this application by utilizing readily obtainable measurements and conventional control components. The steam pressure controller regulated the air for both fuels, with re-adjusting signals being provided for wood and oil. It can be seen that the re-adjusting signal for oil flow is obtained as before. To obtain the re-adjusting signal for wood, it is first necessary to determine the best substitute for wood flow available. Since BTU release is an index of BTU input, the steam flow generated by the wood is used as a measure of wood fed to the furnace. This wood steam flow is obtained by subtracting oil BTU input from total steam flow. It is then ratioed with air to wood which is calculated by subtracting air to oil from total air flow to both fuels. The resulting steam flow/air flow re-adjustment is quite reliable since the BTU release per lb. of air, when properly burned with the wood, is very nearly constant regardless of the heating

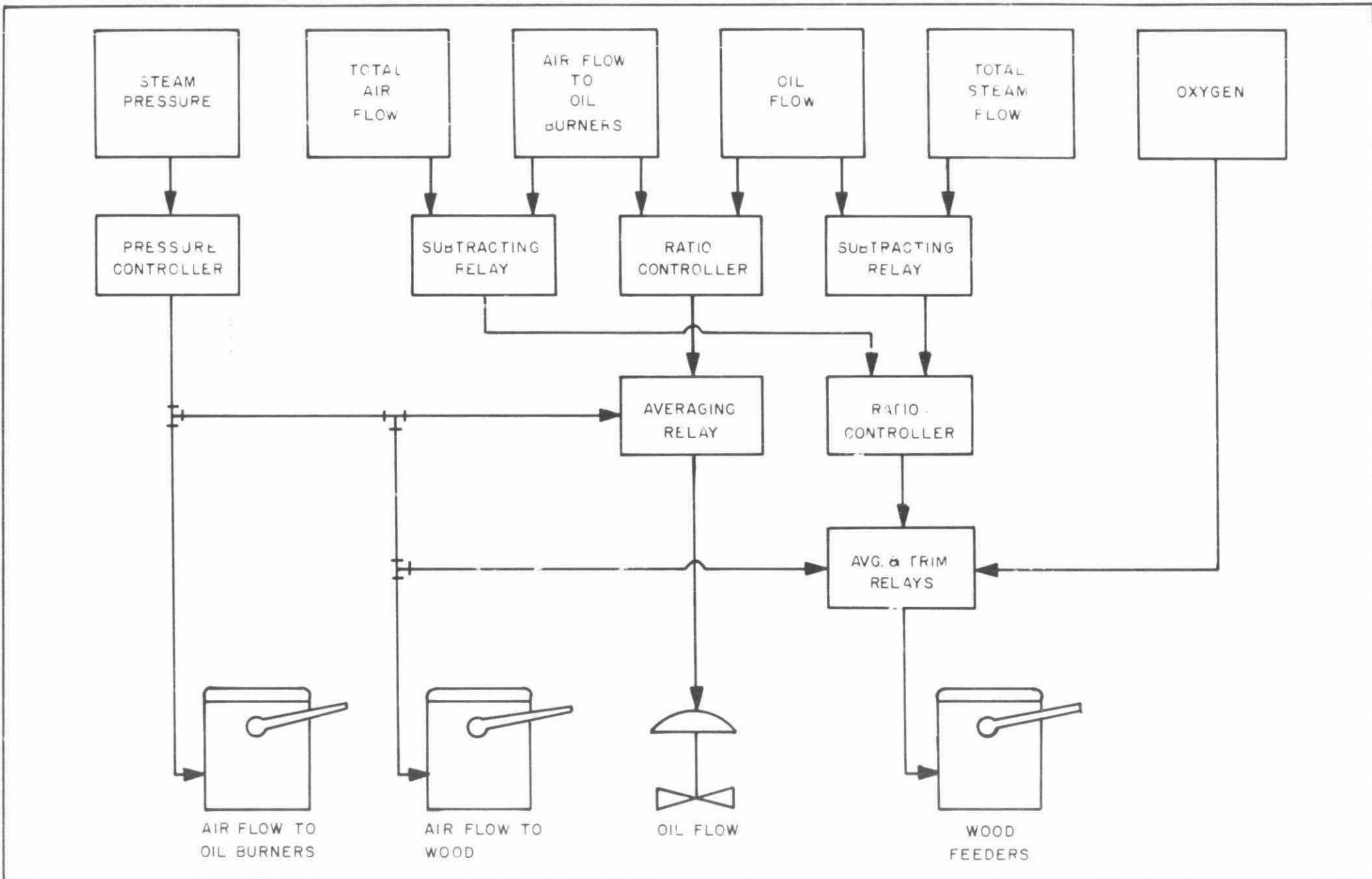


FIGURE 8 - 3 COMBUSTION CONTROL - WOOD AND OIL FIRING

value of the wood. By means of the averaging relay, this ratio signal is used to re-adjust the demand signal to the wood feeders.

8.8 Let us now consider a boiler in which another combination of fuels is to be fired. The fuels involved are blast furnace gas, coke oven gas, and oil. It is desired to obtain maximum utilization of the low cost fuels. This is to be achieved by firing blast furnace and coke oven gases to the maximum limit of their availability, supplementing them only when necessary with oil. Such a unit could be found in most steel mills where the burning of these generated fuels further reduces overall operating costs. The problems to be considered with this unit are:

1. How to ratio the fuel and air with three fuels, always supplying sufficient air regardless of the fuel mixture
2. How to limit blast furnace gas and coke oven gas in accordance with availability of an excess of these gases
3. How to select automatically and continually the most economical combination of fuels allowable

The measurements and basic control actions necessary to achieve these results are illustrated diagrammatically in Figure 8-4. All three fuels are easily and accurately measured, and thus the standard fuel flow/air flow adjustment can be used. Total air flow is measured by sensing the drop across the air heater or by means of a venturi in the air duct. Gas pressure is used as the availability index.

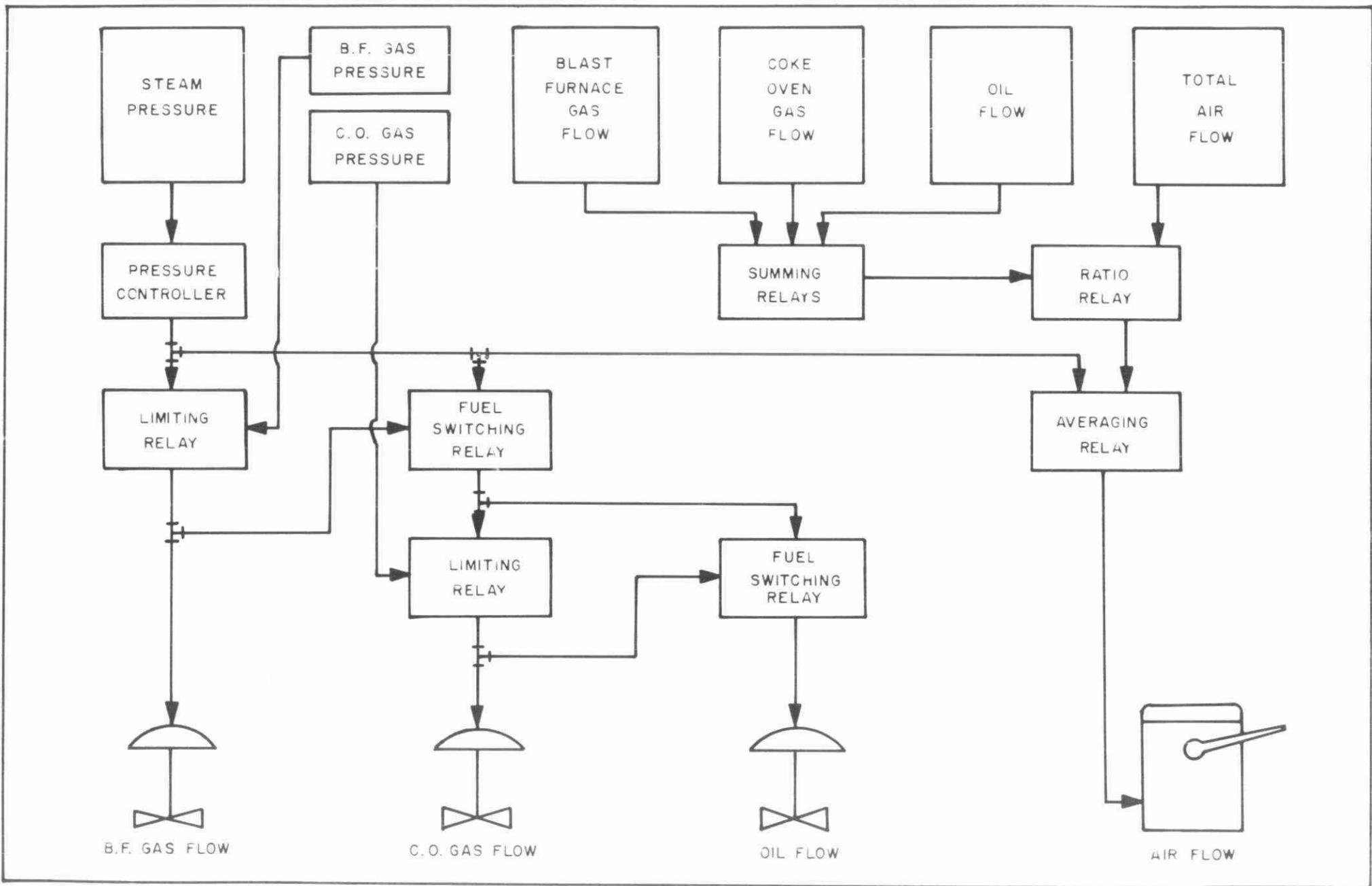


FIGURE 8-4 COMBUSTION CONTROL - BLAST FURNACE GAS, COKE OVEN GAS AND OIL

In order to ratio the fuel and air it is first necessary to obtain a total fuel flow signal. The three fuels are, therefore, totalized or combined on an air required basis in a summing circuit. The resulting signal is then compared to that for total air being supplied.

If the ratio deviates from that desired, a re-adjusting signal is combined with the master pressure demand signal to provide sufficient air with the fuel mixture being burned.

The limiting and fuel switching parts of the system operate in conjunction with each other to provide the most economical fuel mixture allowable. These can be best understood by considering their response to a condition change. For example, assume that we are firing the unit at high load on blast furnace gas, while within its limit. Suddenly, due to decreasing supply, sensed by the gas pressure transmitter, the master demand signal is cut back by the limiting relay in the blast furnace gas control circuit. This reduces blast furnace gas flow. However, as the demand has not changed, it is necessary to make up for the deficiency of BTU supplied. Before the change, the fuel switching relay was balanced by the master signal and the signal to the blast furnace gas valve, as these signals were identical. This balance, now upset by the limiting relay, brings on coke oven gas in sufficient quantity to restore the required BTU input. The fuel/air ratio circuit would simultaneously change the air flow as required for the new fuel mixture. If the availability of blast furnace gas continues to decrease, more and more coke oven gas is used until it too reaches its limit. The resulting

cut back of coke oven gas by a limiting relay will upset the balance of the oil fuel switching relay, thus admitting oil flow to the furnace. As the excess supply of low cost fuels increases, they will again take over in the least costly combination permitted.

Flame Failure Controls

8.9 With the introduction of automatic oil burners, it became necessary to design controls to shut off the fuel and air supply if the burner failed to ignite during starting, or if the flame went out while the burner was running. Without flame failure protection the firebox would fill with an explosive mixture of fuel and air within seconds after the flame had failed.

The first flame failure safeguard was drip pots or pans below the burner nozzle. When these receptacles had collected sufficient unburned oil, the weight of the excess oil operated linkage that closed the oil shut-off valve. This was not a positive control.

The next devices were thermal, or heat operated, such as the "stack" switch. This often was represented by a bimetallic coil in the breeching or chimney. Application of heat to this coil caused it to unwind, operating a switch that permits oil to flow to the burner as long as the coil is hot. If the flame fails, the coil cools off, winds up, shutting off the fuel by means of the switch. These devices were also not positive, because they were slow acting under lack of heat. Also, they did not act until the heat in the breeching had lowered considerably and the presence of soot delayed the action.

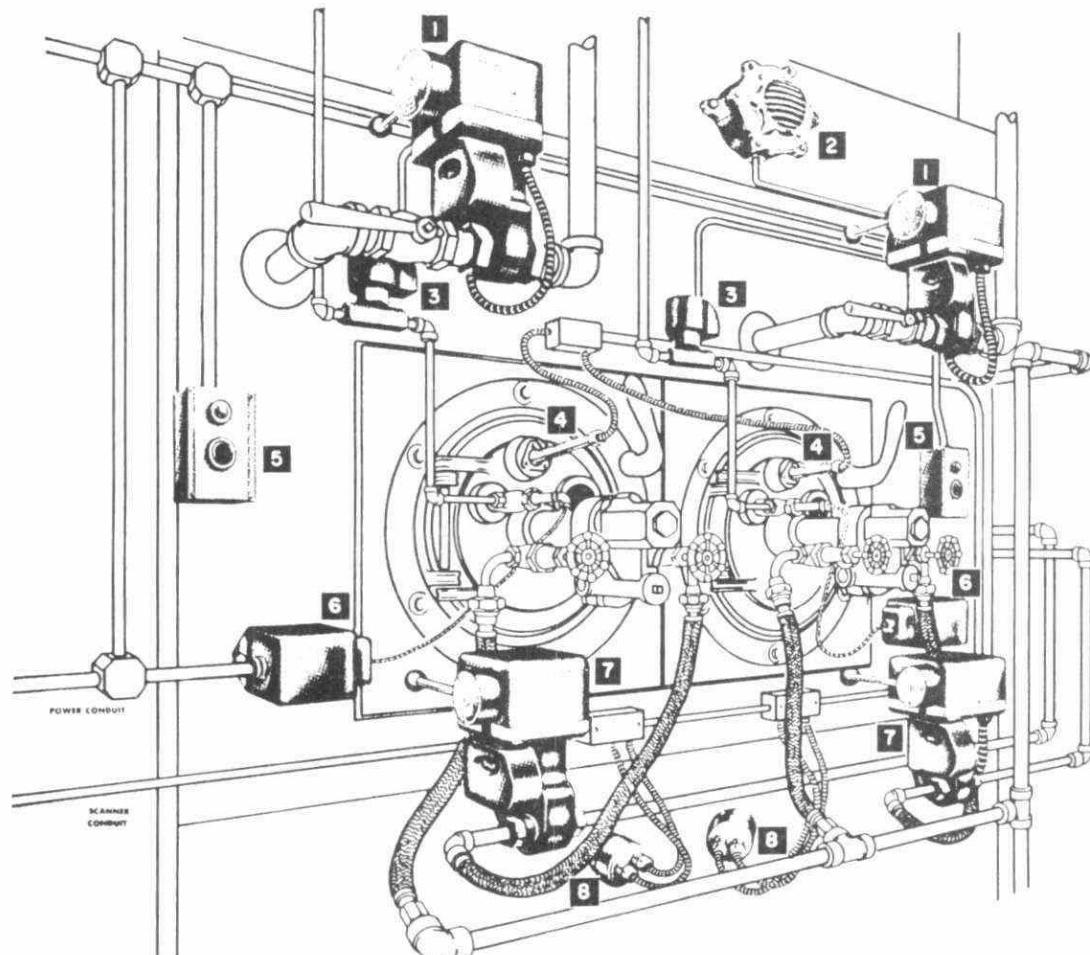
To speed up the detection of flame failure, photo-electric devices were developed. In the beginning, photo-tubes were used, the light of the fire actuated a photocell and energized a relay. The response was good from a yellow flame, but not from a blue flame or a pilot flame. Sometimes the response was too good from red hot fire bricks so that a hazard was created.

Later, flame rods were developed and these depend on the ability of the flame to set up tiny electric currents. This device grounded an electronic circuit from contact with the flame. The gas flame carried the electrons to the burner nozzle and to the ground. However, flame rods were not reliable, the rods would carbon up the resistance changer and the relay dropped out, and the flame rod would often burn out. The electric circuit was not always stable and was sensitive to dust, moisture, or temperature changes. Flame rods were also difficult to install and were often disconnected after a short period of use.

Another development included lead sulphide cells, electronic or photoscanner eye conductive cells that are sensitive to the infra red radiation given off by a fire. The lead sulphide cell reacts to the infra red which envelops every flame - a match, gas flame, an oil flame, or an exhaust. The practicability of this unit rests on an electronic circuit which receives voltage variations based on a varying resistance of the lead sulphide cell, received when exposed to a flame. The electronic circuit will accept and amplify only those voltage variations that correspond to the flicker frequency of the flame. This is probably one of the best types of flame failure safeguards for gas or oil

burners, especially if an orifice is used to screen out the reflected rays from the refractory. A later development uses an electronic control operated by the ultraviolet rays of the flame.

8.10 Figure 8-5 illustrates pictorially the controls for a gas or oil burner installation as viewed from the front of the burner.

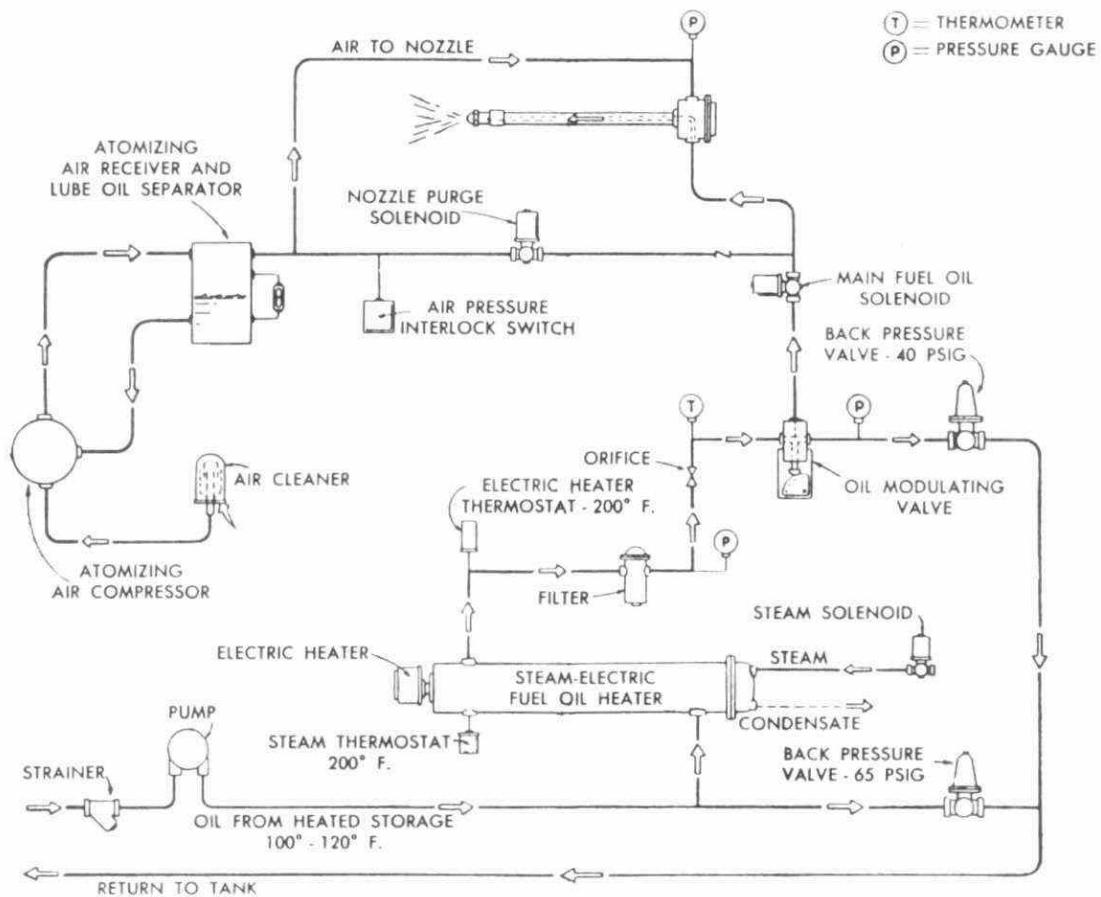


- | | |
|---|---|
| 1 MAIN GAS VALVE — manual reset type, one per burner.
2 ALARM HORN — signals flame failure + heavy-duty industrial type.
3 PILOT GAS VALVE — solenoid type, one per burner.
4 PILOT FLAME SCANNER — Emission type, one per burner. | 5 START SWITCH AND PILOT INDICATOR — push-button operated, momentary contact, one per burner.
6 IGNITION TRANSFORMER — one per burner.
7 MAIN OIL VALVE — manual reset type, one per burner.
8 MAIN FLAME SCANNERS — Emission type, one for each main fuel of each burner. |
|---|---|

Controls for Gas or Oil Burner Installation.

Figure 8-5

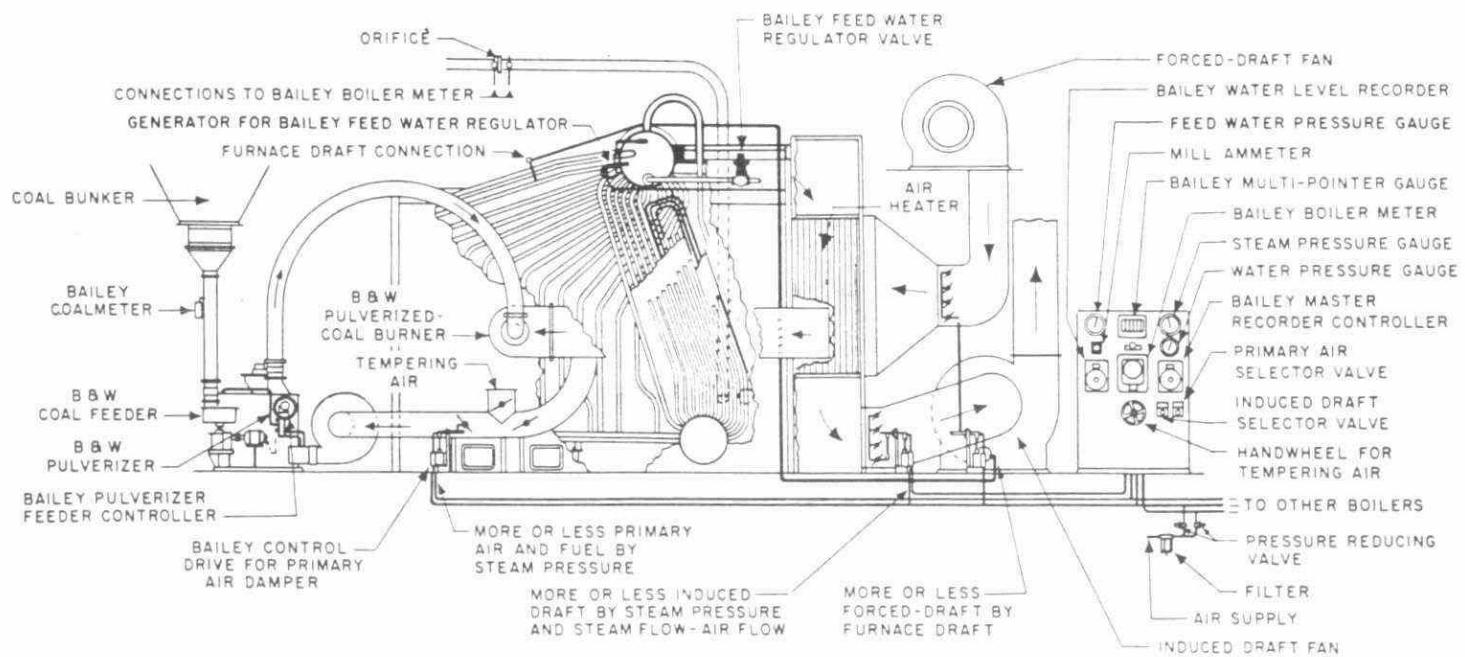
8.11 Figure 8-6 shows control equipment for a modern packaged boiler using Bunker C fuel oil.



Piping and control equipment for a modern packaged boiler using Bunker C Fuel Oil.

Figure 8-6

8.12 Figure 8-7 illustrates a control system for a pulverized coal-burning boiler complete with all normal coal-handling equipment and boiler auxiliaries.



Bailey Meter Control System.

Figure 8-7

SUBJECT:

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

TOPIC: 9

INCINERATION AND
INCINERATORS

OBJECTIVES:

The trainee will be able to:

1. List any six factors or operating conditions which will influence the design of an incinerator;
2. List any 10 of the 14 things to look for when faulty incinerator operation is encountered;
3. Briefly describe the construction and operation of a multiple-chamber incinerator;
4. Briefly describe the process of pyrolysis-combustion.

INCINERATION AND INCINERATORS

9.1 Waste - where did it all begin? Since, "In the beginning God created Man", the problems of waste disposal have multiplied like the growth of a spreading disease; each time a solution is fixed, the problem divides, and we realize that we are no closer to our original purpose. From early times in history it is revealed that people were instructed by their governments, as did Moses instruct the Jews, to bury certain types of waste and to burn the remaining wastes and refuse.

The people in India, and in ancient Rome, had laws prescribing the method and place of disposal of waste material or refuse. Burying of waste material is still practiced by many communities. Gullies are filled with refuse and then covered with earth. In flat low lands, ditches are dug. The refuse is dumped into a ditch and is covered with earth from a second ditch, dug parallel to the first. This sequence is repeated and is called Sanitary Landfill.

Over the years, many ways have been tried for disposal of waste. Common among these are open dumps, sanitary land fills as previously described, processes involving decomposition, rendering, incineration, water disposal, animal feeding and so forth. All of these have been tried with a greater or lesser degree of success depending upon conditions in the local area where tried.

9.2 Generally speaking, incineration at the site of the origin of the waste seems to be the most promising, quick method of disposal presently available to us today.

Each of the other methods have characteristics which may incline them to be more favourably accepted by one or another locality but in the sense of disposal of the larger amounts of waste, incineration seems to be the most acceptable. The importance of incineration lies in its ability to reduce to an absolute minimum the ultimate residue of waste as an inert, sterile ash, be it originally generated as municipal, industrial, residential, or contaminated waste, such as is generated from hospitals, laboratories, etc. If disposing of waste at its source, or site, is to be considered as an efficient operation, it behooves us to reduce it to an absolute minimum as ash, and, thereby, reduce the cost of labour, handling, equipment and hauling of such residue. Complete reduction of waste, in addition to lower cost, allows a broader area for final disposal.

Inert residue with a minimum of organic matter can be disposed over unlimited area. On the other hand, residue that is extensively organic requires greater care in the selection of a site and the manner in which it is buried or covered for final disposal.

9.3 About 1870 Engineers in England began building furnaces to burn refuse. These furnaces were Municipal Incinerators; prior to that time, most of the burning had been done in open pits which, of course, is not an efficient way as some refuse cannot be burned completely in an open fire.

As cities grew in population and area, hauling refuse became more expensive due to longer distances between the source of the waste material and the municipal incinerator. Fire and health ordinances became stricter. Storage space and containers were expensive, consequently refuse storage became a problem.

This problem brought the development of industrial, commercial and, finally, the domestic incinerators, thus allowing the owner to burn his refuse and waste locally, where it was generated.

9.4 Generally, incinerators are required to perform satisfactorily over a wide range of operating conditions. For example, the refuse charged to them is a mixture consisting of different kinds and proportions of solid and semi-solid wastes, consequently the heat of combustion and the burning characteristics may vary widely.

They are further expected to burn the refuse to ashes, without the emission of smoke, bad odours, fumes, ash, charred materials, embers, sparks and the release of toxic pollutants. Unfortunately, air pollution, by incineration, has been and is presently a major concern to any air pollution control department. The two major causes being, (1) poor and improperly designed incinerators, and/or (2) improper operation. The latter probably is the primary reason for over 50 per cent of all incinerator complaints.

Incinerators are designed to be charged at random intervals with varying quantities of refuse, changing the flow rate and distribution of air through and above the ignited charge, with the result that the effective temperatures within the primary chamber fluctuate widely. The above is considered when an installation is in the design stage; however, every ounce of effort, for a well-constructed unit, is wasted when the operator decides to over-charge because he wishes his second cup of coffee, or he decides to leave ajar the charging door to remove a little of the morning dampness of his

surroundings, or he, and the list is endless.

9.5 And so, the evolution of the incinerator. From flue-fed units, to the single-chamber unit, and the addition of a secondary chamber for secondary combustion; to the multi-chamber unit which then had a third chamber for the settling out of particulate matter which might be gas borne; to the addition of auxiliary equipment which included burners for greater efficiency in igniting and drying various wastes, supporting secondary combustion with higher temperatures and the addition of scrubbing devices, whether they be wet or dry. Even then, the efficient function of an incinerator is solely dependent on the care extended by the operator.

Incinerator Design

9.6 Before an incinerator can be designed it is necessary to know the type of waste it must burn, and also local conditions which will influence its operation, such as the number of charges per hour and the amount of waste to be charged at one time. The volume of the material and not weight may be the determining factor in sizing the unit, or maybe the dimensions of one object to be charged will determine the size. Local conditions such as floor or ground area, and height restrictions, may directly affect the incinerator design. The size of the unit would be affected by the number of hours per day the incinerator would be operated. An incinerator rated 500 lb./hr., for example, cannot be charged with a full 500 lb. at one time. Incinerators are designed on the basis of 4 or 5 charges per hour in order to burn at capacity. "Criteria for Incinerator Design and Operation" in Ontario were prepared by the

former Air Management Branch of the then Department of Energy and Resources Management and were published in May, 1970.

Faulty Incinerator Operations

9.7 The following will serve as a check list of things to look for when faulty incinerator operation is encountered:

1. Does material being burned conform to the specifications both as to quantity and type of refuse
2. Is the unit being charged a minimum of 4 times per hour
3. Are draught openings open to provide combustion air
4. Is ash pit reasonably clean to allow air free access to underside of grate
5. Are grates clean so that air gets to fuel
6. Are dampers, if any, adjusted to give adequate draught and active flame
7. Is settling chamber reasonably clean
8. Is fuel bed loose so that it can burn readily
9. Are stack and breeching free of obstructions
10. If burner or burners are specified are they in operation

11. Was unit pre-heated before being charged
12. Is spark arrestor screen plugged
13. Is sufficient air available in incineration room for combustion requirements
14. Was too much material charged at one time

Incinerators

9.8 An incinerator is essentially a heat resistant enclosure with provision for the introduction of combustion air. The same basic principles of combustion apply to the incineration of refuse as they do to other fuels.

Incinerators are classified as "single" and "multiple" chambers. Both types may involve auxiliary aids to combustion, such as gas or oil burners, forced draught blowers, continuous feed systems, moveable grates, ports, doors and dampers for control of secondary air, and spark arrestors.

Single Chamber Incinerator

9.9 This is a device in which one chamber serves ignition, combustion, and ash removal, partitioned only by a fixed or moveable grate. Since this type of incinerator fails to provide the conditions necessary for complete combustion (it is quite often nothing more than an enclosed open fire), the control of smoke, fumes and fly-ash in its operation is uncertain.

Most single-chamber incinerators are not designed to control air pollution, but to dispose of rubbish. As a consequence, the widespread use of these incinerators

in a large metropolitan area causes significant amounts of smoke and odour pollution.

The most common example of this type of incinerator is the apartment house flue-fed incinerator (Figure 9-1). In these the smoke flue also serves as the depository for refuse at the respective floors of the apartment building. The control of such incinerators is essentially the finding of suitable alternative means for refuse disposal or more efficient types of combustion equipment.

Multiple-Chamber Incinerators

9.10 Multiple-chamber incinerators are designed for the purpose of providing efficient and maximum combustion of the material being burned, and hence less emission of smoke, fly-ash, and volatilized gases over a wide (though limited) range of operating conditions. These incinerators are constructed in a series of three chambers interconnected by flame ports; (1) a charging (or ignition) chamber for the initial lighting and burning of the material, (2) a "mixing" chamber providing the turbulence and temperature necessary to consume incompletely burned or organic materials, and (3) a secondary combustion chamber for organic gases and the settling of fly-ash. The multiple-chamber incinerator is constructed according to the basic design principles in relation to the type of material and the rate at which it is being burned for the use intended. In particular the relationship of grate loading to combustion rate, and arch height to the grate area in the ignition chamber, are considered to be critical. Underfire air, which is normally used to obtain high fuel bed temperatures in other types of combustion equipment, is maintained to prevent volatili-

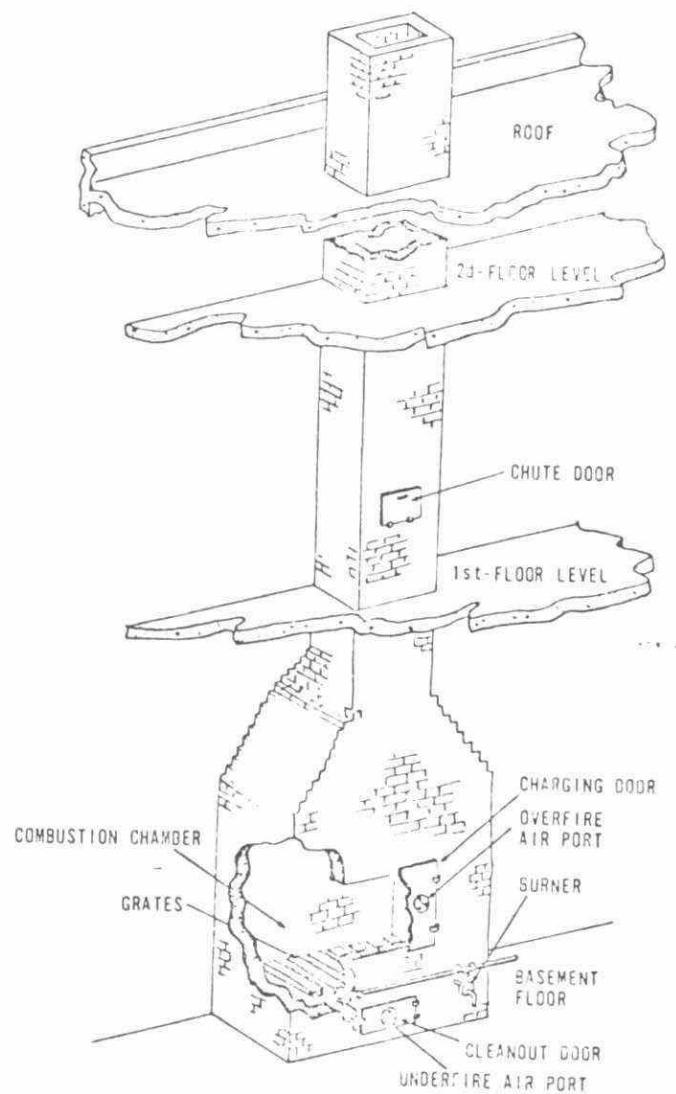


Figure 9-1 Unmodified flue-fed incinerator
(MacKnight et al., 1980).

zation of inorganic materials. Overfire air on the other hand is used to promote surface combustion and to prevent ash entrainment. In addition, additional secondary air and additional flame coverage may be supplied to the mixing chamber when required.

There are two general types of multiple-chamber incinerators, the "in-line" type (Figure 9-2), usually used in the larger installations, and the "retort" type (Figure 9-3), usually used in the smaller installations. Portable type multiple-chamber incinerators are of the "retort" type.

As the name suggests, the "in-line" type is constructed with the three chambers one behind the other - "in-line". The "retort" type is a more compact design so constructed that the mixing and secondary combustion chambers are alongside the charging or ignition chamber.

Multiple-chamber incinerators have a good capability for smokeless combustion, but they can smoke excessively through careless operation, by exceeding rated capacities, by burning unauthorized materials, or through neglect of any of the conditions necessary for complete combustion outlined previously.

Tables

9.11 Table 9-1 is a suggested list of operating rules for optimum incinerator efficiency. Tables 9-2 and 9-3 show the approximate combustion characteristics and bulk densities, respectively, of various waste materials. Table 9-4 lists approximate quantities of refuse from various sources.

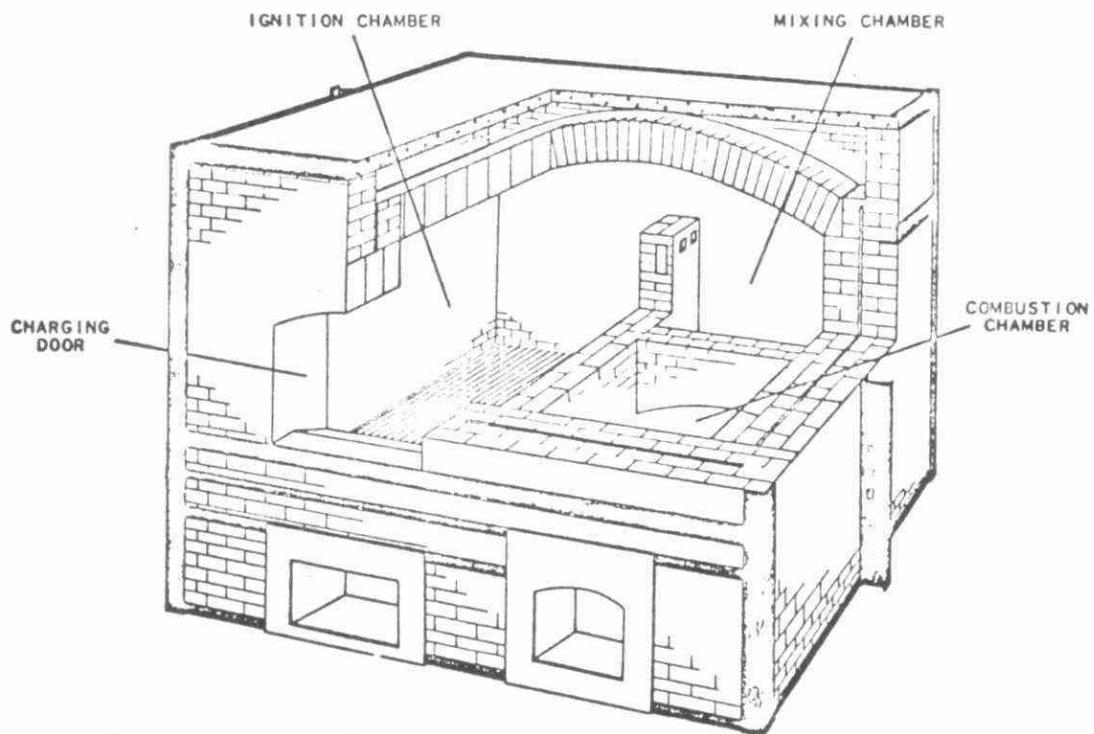


Figure 9-3 CUTAWAY OF A RETORT MULTIPLE-CHAMBER INCINERATOR

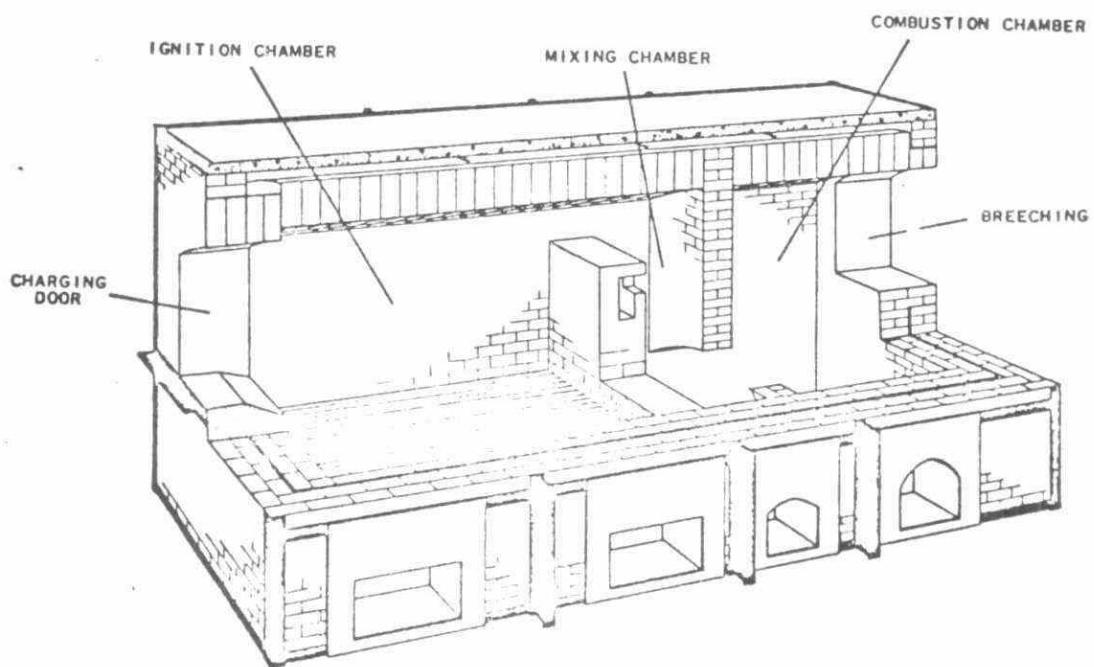


Figure 9-2 CUTAWAY OF AN IN-LINE MULTIPLE-CHAMBER INCINERATOR

(Courtesy Los Angeles County Air Pollution Control District)

Table 9-1

Suggested List of Operating Rules
for Optimum Incinerator Efficiency

1. Incinerators must be operated only by a competent operator, who shall be on hand throughout the burning period
2. Auxiliary burners must be turned on 30 minutes before ignition of refuse, and must be kept in operation throughout the burning period
3. Operate incinerator only when it is two thirds or less full, and do not burn materials which are likely to smoke or smoulder, e.g. rubber, plastic or materials with a high moisture content
4. Ignite refuse from the top, then close doors and keep them closed throughout operation
5. Regulate draught to avoid excessive burning rates and smouldering, and, wherever possible, burn refuse without raking the fire
6. Keep ash pit, grates, and area around incinerator clean. Leave 10 or 12 burned cans on the grates after dumping
7. Allow fire to cool and close the fire and ash pit door before dumping grates
8. To clean settling chambers use a vacuum cleaner, or wet down dust with a fine spray before removal. Clean chambers at least every two months
9. Keep all parts of the incinerator clean and in good repair at all times

Table 9-2

Approximate Combustion Characteristics
of Various Kinds of Waste Materials

Substance	High heat value, ^a Btu/lb. maf ^b waste	Theoretical air needed for complete combustion, ^c lb. air/lb. maf waste
Paper.....	7,900	5.9
Wood.....	8,400	6.3
Leaves and grass.....	8,600	6.5
Rags, wool.....	8,900	6.7
Rags, cotton.....	7,200	5.4
Garbage.....	7,300	5.5
Rubber.....	12,500	9.4
Suet.....	16,200	12.1

^aThese values are necessarily approximate, since the ultimate composition of the combustible part of the materials will vary somewhat, depending upon their sources. The heating value of the as-received material is obtained by multiplying the maf Btu by 100-(percentage moisture and ash)/100. For example, garbage containing 35 per cent moisture and 5 per cent ash or other noncombustible material will have an as-fired heating value of 4,380 Btu/lb.

^bMaf means moisture-and-ash free, where ash refers to total noncombustible material.

^cThese values are also approximate and are based upon 0.75 lb. air/1000 Btu for complete combustion. For various percentages of excess air, multiply these values by (100 + per cent excess air)/100. For example, if paper is burned with 100 per cent excess air, $(5.9)200/100 = 11.8$ lb. air/lb. of maf paper will be required.

Table 9-3

Approximate Bulk Densities of Various Wastes^a

	Lb/cu ft	Lb/cu yd	Lb/bu
Paper, loose.....	5	135	7
Rubbish.....	10	270	13
Refuse.....	16	440	21
Wood scraps, air-dried.....	15	400	20
Wood shavings or sawdust, air-dried.....	10	270	13
Garbage.....	35	945	45

^aThese are average values. Bulk densities will vary with the degree of compactness and the moisture content of the charge. For example, the lowest and highest values found in a survey of garbage were about 30 and 57 lb/cu ft. respectively. For refuse, the lowest and the highest values were about 7 and 30 lb/cu ft. respectively. Satisfactory preliminary engineering estimates for incinerator design may be made with the average values given above.

Table 9-4

Approximate Quantities of
Refuse from Various Sources

<u>Source</u>	<u>Daily Quantity of Refuse</u>
Apartment buildings having 1- and 2 1/2 room apartments	1 to 1 1/2 lb per person
Apartment buildings having over 4 rooms per apartment	2 lb per person
Hotels	2 lb per guest room plus 2 lb per meal
Cafeterias	1/2 pound per meal
Restaurants	1 lb per meal
Hospitals	7 lb per meal
Schools	8 lb per classroom

Controlled Air Incinerators (Figures 9-4 & 5)

9.12 As municipalities saw the need for adopting some type of control, and areas where existing codes required the need for more stringent abatement laws, pressure began to be exerted on the manufacturers of incinerator equipment. This then is what gave impetus to the development and improvement of incinerators employing the controlled air concept as a method of disposing of solid wastes. Controlled air incineration is not a totally new concept; as a matter of fact, as early as the late 1800's, patents were applied for. However, the controlled air concept permits a level of control of all the various parameters normally considered in a combustion process, so that the combustion process can continue under conditions of extremely low stack emissions.

Simply, it may be described as a process of pyrolysis-combustion. Webster defines pyrolysis as "a chemical change brought about by the action of heat, the breaking down of solids to gases, in the absence of oxygen", and "combustion as an act or instance of burning".

The process of pyrolysis-combustion is the breaking down, or volatilization of solid wastes in the presence of less than 100 per cent stoichiometric air. Complete combustion of these gases occurs when mixed with the remaining combustion and excess air and ignited in an afterchamber. The afterchamber could be referred to as a reactor or carburettor.

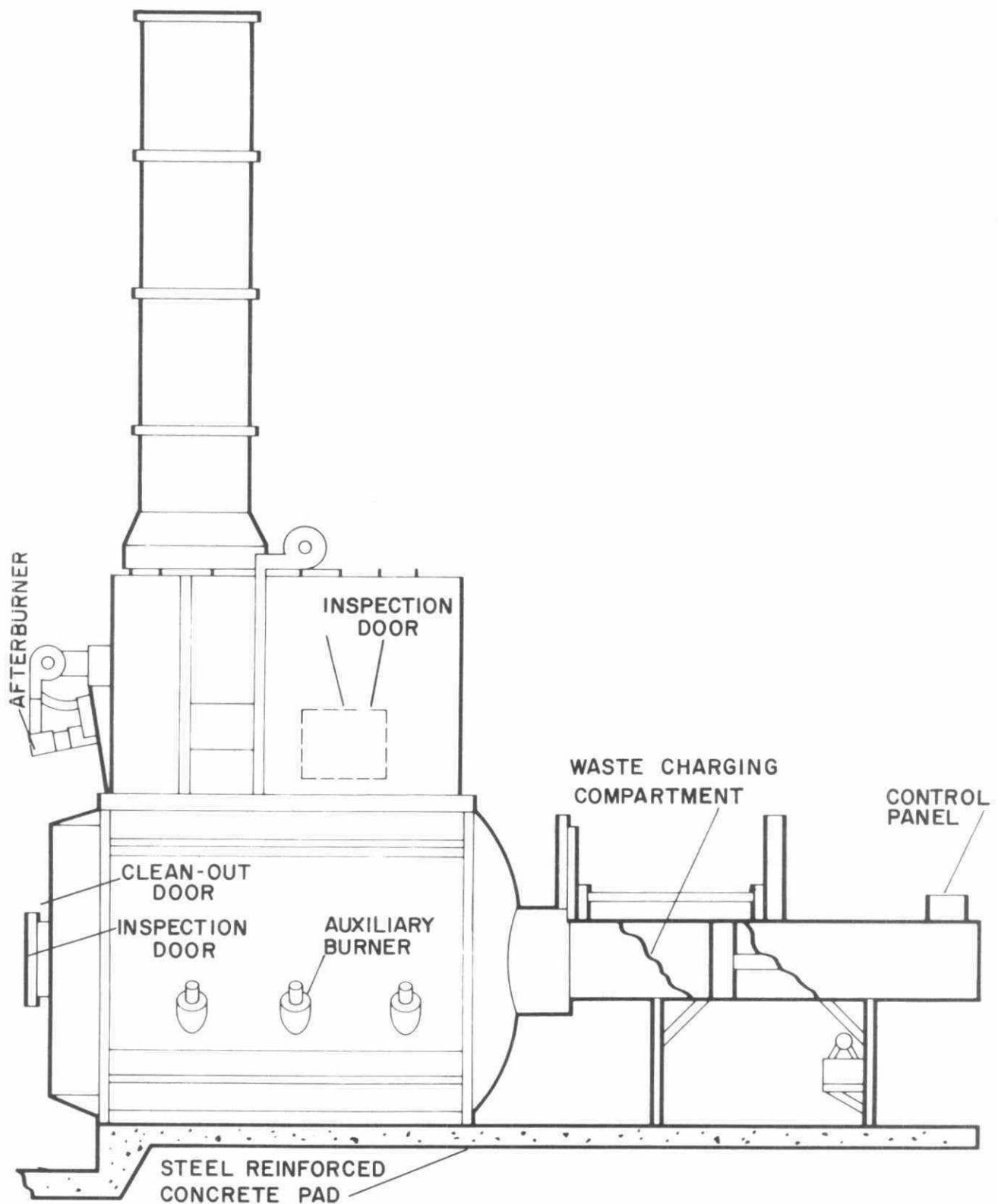


Fig. 9-4 Controlled Air Incinerator
Courtesy of Waste Control Systems Inc.

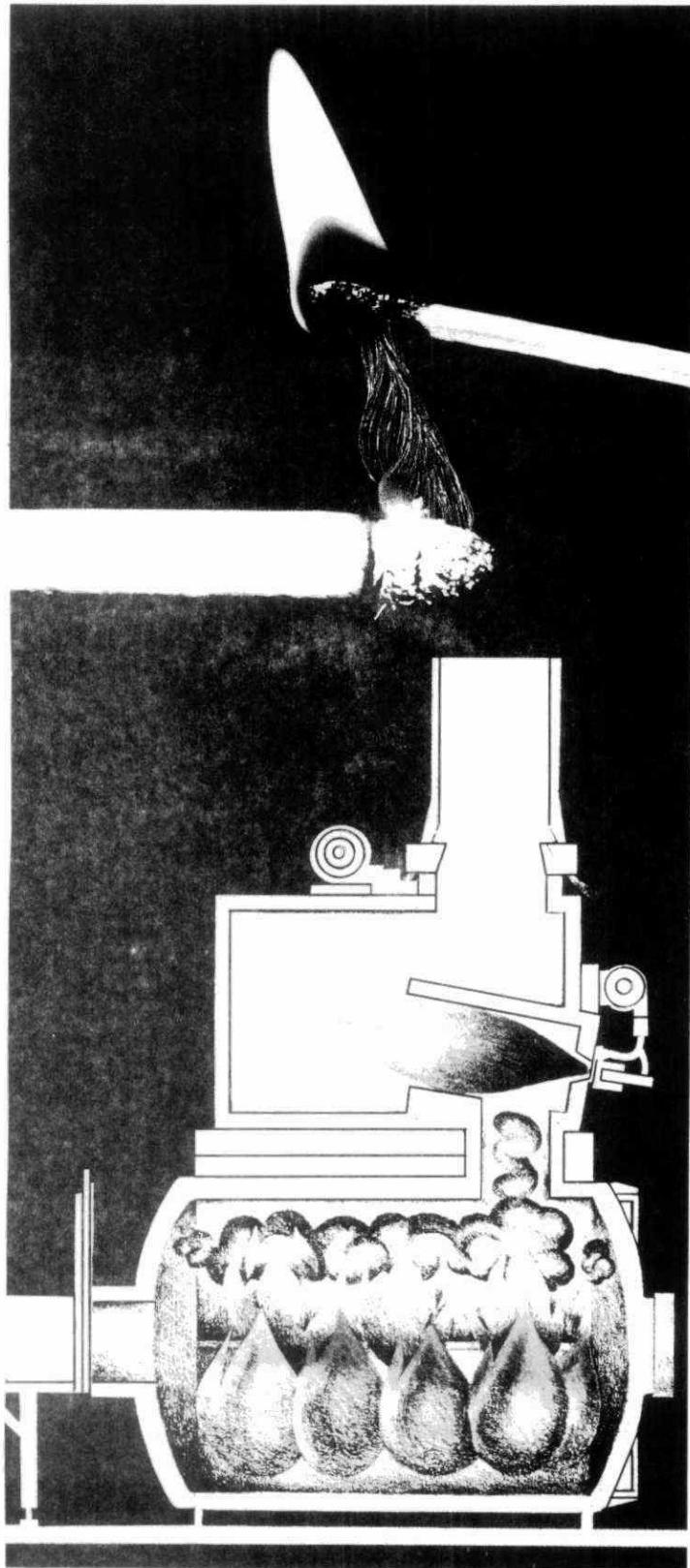


Fig. 9-5 Simplified Diagram of Controlled Air Incinerator Combustion Process
Courtesy of Waste Control Systems Inc.

How combustion is achieved.

The H-760 unit consists of:

1. a horizontal cylindrical-shaped distillation chamber in which the waste is volatilized by partial oxidation;
2. an upper chamber in which the gases generated in the distillation chamber are fully combusted; and
3. an air inductor assembly to lower the stack exit temperatures (no auxiliary pollution control devices required).

The primary burners ignite the refuse in the distillation chamber, into which a small amount of under-fire air is supplied. An afterburner in the upper chamber, into which additional air is forced to mix thoroughly with the hot gases from the distillation chamber, completes the combustion process.

Wood and Bark Residue Incineration

9.13 The manufacture of forest products results in the generation of several types of residues. For example, in making lumber and plywood, less than half of the original log is converted to the primary products in the mills. At sawmills, the remainder of the log is residue in the form of slabs, edgings, lumber trim, sawdust, shavings or bark. In plywood manufacture, residues occur as log trim, green veneer clipping and trim, dry veneer trim, panel trim and sander dust.

9.14 When markets cannot be developed for all residues developed in the manufacture of plywood and lumber, the remaining wood and bark waste must be disposed of in some manner. By far the most common method of disposal of wood and bark waste is by incineration in wigwam burners. These are also referred to as teepee burners, conical burners and wood waste burners.

It consists of a metal enclosure in the form of a truncated cone, topped with a dome shaped screen. In operation, fuel is dropped onto a pile inside the burner from a conveyor above and air is supplied to the combustion zone from openings at the base of the burner. Sometimes, fans and grate systems are used.

The most common size of burner is one with a 50 foot diameter and approximately 50 feet in height. The shell is formed of sheet steel and it is common to find long seams opened up and occasionally sheets missing. Underfire air is supplied under the wood pile and is usually delivered at about 6 inches minimum static pressure at the nozzles. Quantity of underfire required is about 2500 scfm per ton of oven dried wood waste per hour.

The purchase and operation of the wood waste burner represents an unrecoverable expenditure and management usually pays little attention to maintenance. Inspections usually reveal the aforementioned loose sheeting plates, clogged underfire air nozzles, large accumulations of ash, open access doors and the spark screen in poor repair. It has been estimated by some authorities that the average wood waste burner was operating with something like 200% excess air.

9.15 Guidelines have been drawn up for the design of conical wood waste burners. In brief, these state that the size of the burner should be proportionate with the wood residue to be burned according to the following formula:

$$D = 2.3 Q^{1/3}$$

where D = Base diameter in feet

Q = Quantity of waste to be burned in lb/hr.
(basis - green pine bark, .5% moisture)

The height of the conical burner should be equal to, or greater than, the base diameter. The guidelines also provide for the quantity of air to be supplied and the design and placement of the air nozzles.

The most critical requirement may be the provision of a temperature recorder controller to maintain a temperature at the top of the burner between 425° and 540°C. The sensor is to be placed 8' below the dome and 1 foot inside the shell.

The guidelines also provide for a trained operator at all times, a feed rate control, auxilliary fuel if the moisture content of the combined feed exceeds 55%, and the placement of the wood waste burners wherever possible at least 2500 feet from significant receptors.

9.16 Problems with emissions from wood waste burners would be: smoke in excess of the Regulations, odour causing some degree of discomfort to persons and particulate in the form of ash, charred particles or fine particles carried out by the draft before taking part in the combustion process. Table 9-5 lists the emission factors for waste incineration in conical burners without controls.

9.17 There are several methods of designing conical burners which will satisfy our requirements. One method uses a variable damper at the top of the burner, auxilliary fuel when necessary, and a separate underfire and overfire air system. Another uses a double wall feature in which combustion air is pulled down between the double walls to pre-heat the air, while others use an inverted cone in the top of the burner to collect particulate for reinjection. One system is illustrated in Figure 9-6.

Other methods are under assessment and it would appear that all will need auxilliary burners at least part of the time, usually during start-up and during extreme load conditions.

Table 9-5 EMISSION FACTORS FOR WASTE INCINERATION IN CONICAL BURNERS
WITHOUT CONTROLS^a
EMISSION FACTOR RATING: B

Type of waste	Particulates		Sulfur oxides		Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Municipal refuse ^b	20(10 to 60) ^{c,d}	10	2	1	60	30	20	10	5	2.5
Wood refuse ^e	1 ^f	0.5	0.1	0.05	130	65	11	5.5	1	0.5
	7 ^g	3.5								
	20 ^h	10								

^aMoisture content as fired is approximately 50 percent for wood waste.

^bExcept for particulates, factors are based on comparison with other waste disposal practices.

^cUse high side of range for intermittent operations charged with a bulldozer.

^dBased on Reference 3.

^eReferences 4 through 9.

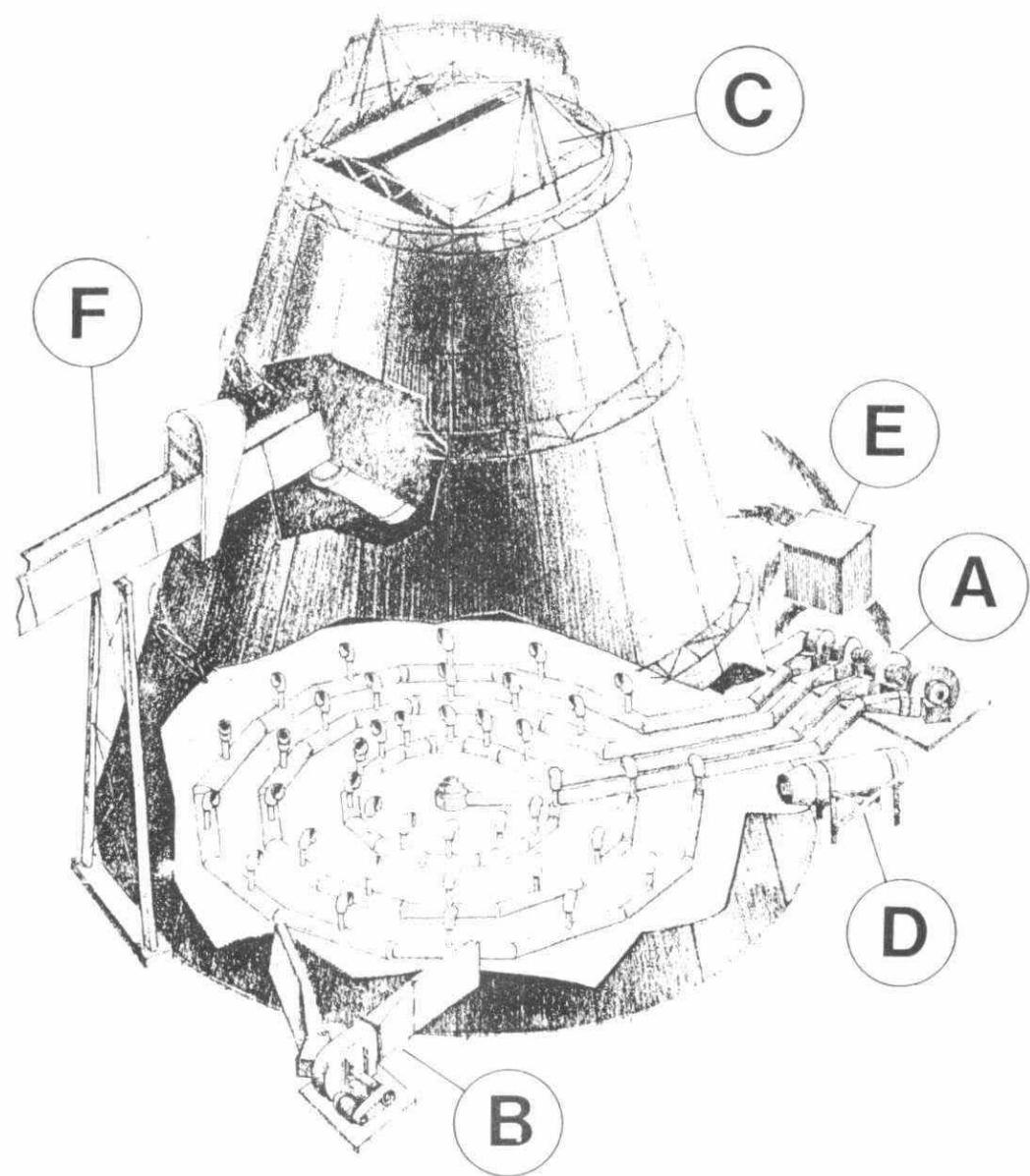
^fSatisfactory operation: properly maintained burner with adjustable underfire air supply and adjustable, tangential overfire air inlets; approximately 500 percent excess air and 700°F (370°C) exit gas temperature.

^gUnsatisfactory operation: properly maintained burner with radial overfire air supply near bottom of shell; approximately 1200 percent excess air and 400°F (204°C) exit gas temperature.

^hVery unsatisfactory operation: improperly maintained burner with radial overfire air supply near bottom of shell and many gaping holes in shell; approximately 1500 percent excess air and 400°F (204°C) exit gas temperature.

High levels of smoke and particulate matter result largely from incomplete combustion. These levels can be reduced to acceptable standards when good combustion is achieved by the proper application of the RM Underfire and Overfire Forced Draft Systems [A] and [B]; the RM Vari-Damper [C]; the RM Jet-Fire Auxiliary Fuel Systems [D]; the RM Electronic Controller [E]; metered fuel feed [F]. These RM controls make possible a high operating temperature that can be set between 650° and 900° F for optimum combustion.

Figure 9 - 6
Conical Burner



SUBJECT:

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

TOPIC: 10

THE FEDERAL PROGRAM FOR
AIR POLLUTION CONTROL

OBJECTIVES:

The trainee will be able to:

1. List the four areas in which the federal government has primary jurisdiction;
2. Summarize the three main objectives of the federal Clean Air Act.

THE FEDERAL PROGRAM FOR AIR POLLUTION CONTROL

A. Introduction

10.1 Air Pollution control has been organized in Canada as a joint Federal-Provincial undertaking. The division of powers has been allocated by Sections 91 and 92 of the British North America Act, the main constitutional legislation in Canada. The BNA Act delegates the primary jurisdiction for air pollution control to the provincial governments. However, several areas exist where the federal government has primary jurisdiction and these are:

1. works, undertakings and businesses with the legislative authority of the Parliament of Canada. This would include federal buildings, institutions, and crown companies.
2. emissions of air contaminants in quantities and concentrations which would constitute a significant danger to the health of persons.
3. emissions of air pollutants which would likely result in violation of international agreements.
4. the composition of fuels or fuel additives.

10.2 The guiding legislation for air pollution control in Canada is the Clean Air Act which was promulgated on November 1st, 1971. The Act has three main objectives:

1. The chief responsibility is the promotion of a uniform approach to air pollution across Canada. Since the direct responsibility for administration of air pollution control falls within the provincial

jurisdiction, the existence of "pollution havens" resulting from differences in air pollution legislation from province-to-province becomes a possibility, and the role of the federal government is then to outline National Guidelines to provide a more uniform approach across the country.

2. The Act has provisions to enable the federal government to enter into agreements with individual provinces for the purpose of facilitating the formulation, co-ordination and implementation of policies and programs designed for the control and abatement of air pollution. This section of the Act is not intended to replace provincial jurisdiction and legislation, but is intended to complement and supplement provincial legislation. An example of federal-provincial co-operation might be joint research programs or the federal supply of monitoring equipment for provincial surveys. A federal-provincial air pollution accord providing for far ranging co-operative efforts is currently being considered by both levels of governments.
3. A third objective of the Act is to provide federal government leadership in areas where federal government involvement is necessary. These areas have included:
 - (a) A national inventory compilation of source emission data for various pollutants.
 - (b) Establishment of national air quality objectives.

- (c) Control of air pollution from federal government establishments and businesses under federal legislation.
- (d) Control of fuel composition and fuel additives (i.e. lead additives in gasoline).
- (e) Co-ordination of a national air pollution surveillance network.
- (f) Development of federal emission guidelines.
- (g) Development of Federal Emission Regulations.

Each of these activities is described in the following section.

B. National Inventories

10.3 Section 3 of the Act refers to the Minister's mandate to collect and publish data on air pollution.

One of the first actions taken was to contract with an outside consultant for the compilation of a National Emission Inventory for five major contaminants: sulphur dioxide, particulate matter, carbon monoxide, hydrocarbons and nitrogen oxides using 1970 as the base year. This inventory is available as report EPS-3-AP-73-1.

Also completed at an early date was an inventory of hazardous pollutants, namely asbestos, beryllium, lead and mercury, and a summary of the report is available as EPS-3-AP-74-1.

At the present time inventories are being prepared for arsenic, cadmium, fluoride, manganese and vanadium.

These inventories are useful for the definition of problem areas and are used for the determination of priorities for guideline and regulation development.

C. Air Quality Objectives

10.4 Section 4 of the Act provides for the formulation of ambient air quality objectives in terms of three ranges of quality namely, the tolerable range; the acceptable range; and the desirable range.

The development of these objectives has been the responsibility of an expert Subcommittee of the Federal-Provincial Committee on Air Pollution.

At this time the acceptable and desirable objectives have been set for five common pollutants, i.e. sulphur dioxide, suspended particulates, oxidants (ozone), carbon monoxide, and nitrogen dioxide, and these are appended.

The question of maximum tolerable range continues to be examined under the direction of the Federal-Provincial Committee.

D. Federal Facilities

10.5 Sections 10 to 18 of the Act refer specifically to the control of air pollutants from Federal Facilities, and describes the criteria by which the sources are to be evaluated and controlled.

There are specific groups of people both in Ottawa and the regional offices whose sole concern is the clean-up of pollution problems of federal facilities, and there are substantial funds available for this purpose.

It is important to note that, although there is no formal requirement to comply with provincial regulations, it is the intent to have all federal facilities within Ontario in compliance with provincial, as well as federal regulations.

E. Fuel Composition

10.6 Sections 22 to 26 describes the federal mandate to legislate the concentration of additives in fuel produced or imported into Canada.

There are currently two such pieces of legislation being enforced by Environment Canada. These are

(i) Lead-Free Gasoline Regulations, and (ii) Leaded Gasoline Regulations.

F. National Air Pollution Surveillance Networks (NAPS)

10.7 Section 3 of the Act defines the need for this activity. This network which is operated in conjunction with provincial and municipal governments across Canada, continually measures and records sulphur dioxide; carbon monoxide; nitrogen dioxide; ozone; soiling index; suspended particulates and lead; dustfall; and sulphation rate, in about 40 cities.

This program provides information that can be used to determine trends and the effectiveness of control measures; in the determination of air quality objectives; and in epidemiological studies.

The results of the network monitors are published monthly and as an annual summary.

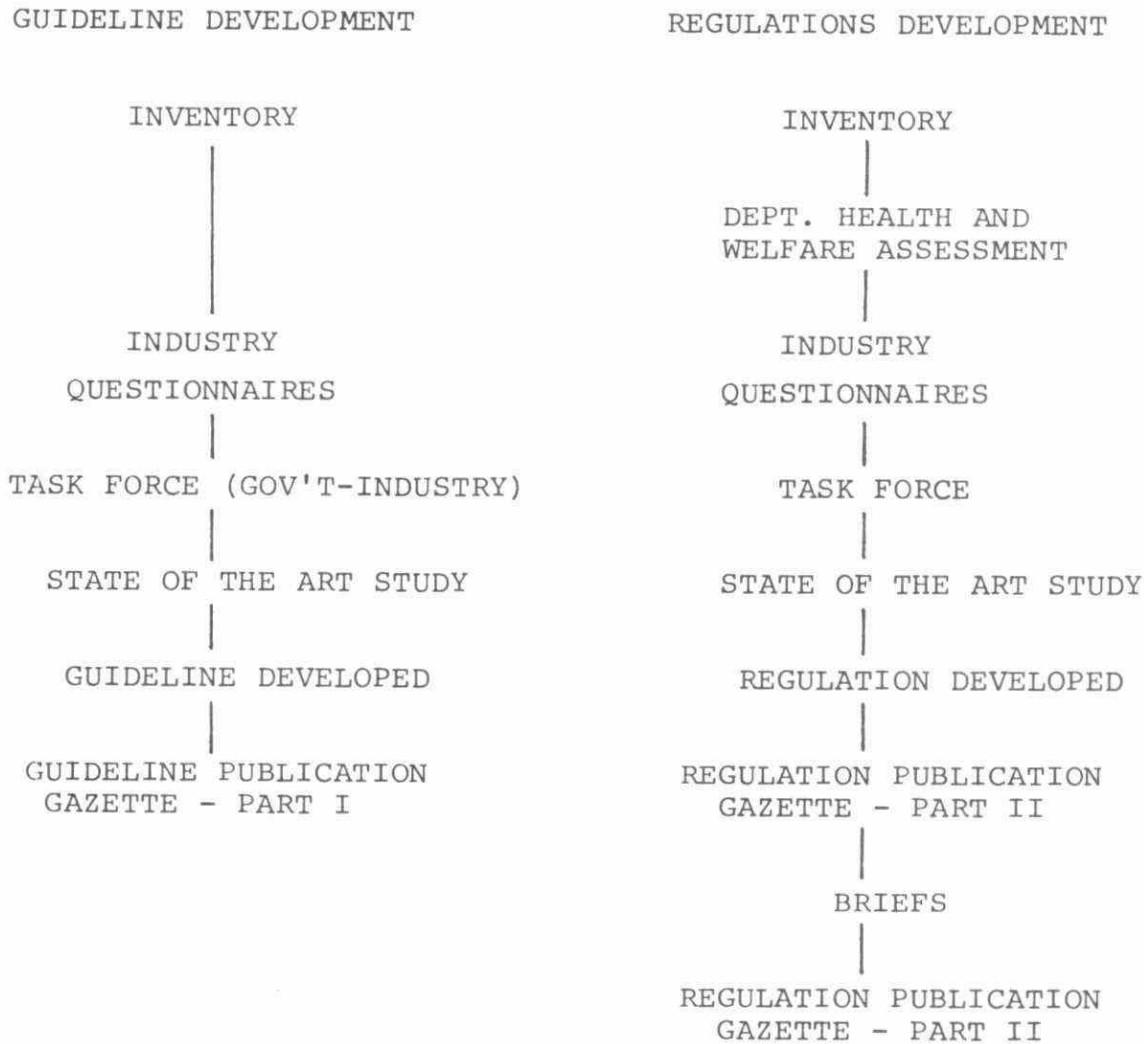
G. Development of Federal Emission Guidelines

10.8 The authority of this activity is Section 8 of the Clean Air Act.

For guidelines development the requirement for air pollution control is the use of "best practicable technology" to attain containment at source. This approach guarantees that plants within an industry are treated alike and promotes a minimum, uniform requirement across the country, nullifying the existence of "pollution havens". In the choice of best practicable technology, the status of the air pollution control technology involved for the industry and the economic considerations are taken into account in adopting the various measures of control.

Guidelines are developed through the mechanism of federal-provincial government-industry task forces (Figure 10-1). In order to obtain information from which to derive guideline numbers, industry information as regards processes, quantitative measures of emissions, degree of existing control measures and economic data are solicited through questionnaires. Plants visits are also made by Environment Canada personnel to update their knowledge of representative plants. Data collected from the questionnaires is used to produce a state-of-the-art study, and one of the duties of the task force is to review this document critically prior to actual guideline development. In assessing the emissions from industry, an attempt is made to provide containment policy adapted to the particular aspects of the various industrial processes involved, i.e. best practicable technology. Prior to publication of the guidelines in Canada Gazette Part 1, representatives of the task force are given sufficient opportunity for discussion of proposed guidelines. As already mentioned, the guidelines are intended to provide a minimum baseline requirement for the industry across the country and local conditions may necessitate more stringent provincial regulations.

FIGURE 10-1



As of September, 1975 the status of guidelines development is as follows:

1. Asphalt mixing plants - guidelines published April 5, 1975.
2. Coke ovens - guidelines published May 13, 1975
3. Chlo-alkali plants - Task Force meetings in progress
4. Iron and steel plants - Task Force meetings to commence in early 1976
5. Pulp and paper - Task Force meetings in progress
6. Incinerators - near completion
7. Ferrous foundries - Task Force meetings to commence September, 1975
8. Ferro-Alloy plants - Task Force meetings to commence mid 1976
9. Portland cement plants - guidelines published October 12, 1975
10. Natural gas processing plants - near completion
11. Non-ferrous smelters - Task Force meetings to commence late 1975
12. Thermal power and diesel generating plants - Task Force meetings in progress
13. Petroleum refining - Task Force meetings in progress
14. Petrochemical & Synthetic Resins - Task Force meetings to commence in early 1976

H. Development of Federal Emission Regulations

10.9 Under Section 7 of the Clean Air Act, any air contaminant which could constitute a significant danger to health, must have its emission rate controlled by regulation. This regulation is then a legal requirement across Canada. Provincial authorities however, still have the option of producing regulations more stringent than the federal regulation.

Regulation development (Figure 10-1) follows after an industry inventory has been conducted for the various pollutants to locate specific problem areas. In the past inventories have been conducted for lead, mercury, asbestos and beryllium. At the present time inventories are in progress for arsenic, cadmium, fluorides, manganese and vanadium. Co-operative efforts are in progress with the Ontario Ministry of the Environment for consideration of the vinyl chloride problem. While regulation development may take the form of a government-industry task force, such as is the case for mercury from chlor-alkali plants, and asbestos from the mine-mill operations, it may also be developed internally by Environment Canada after consultation with other government agencies and industry. An example of this is the proposed regulations for secondary lead smelters. In either case, all interested parties are given opportunity for critical evaluation of proposed regulations by submissions of briefs, after publication of the regulation in Canada Gazette Part 1 and prior to publication in Part 11.

Currently a regulation has been developed for lead from secondary lead smelters, and has been published in Part 1 of the Canada Gazette. Regulations are being developed for mercury (chlor-alkali industry) and asbestos (mine-mill operators).

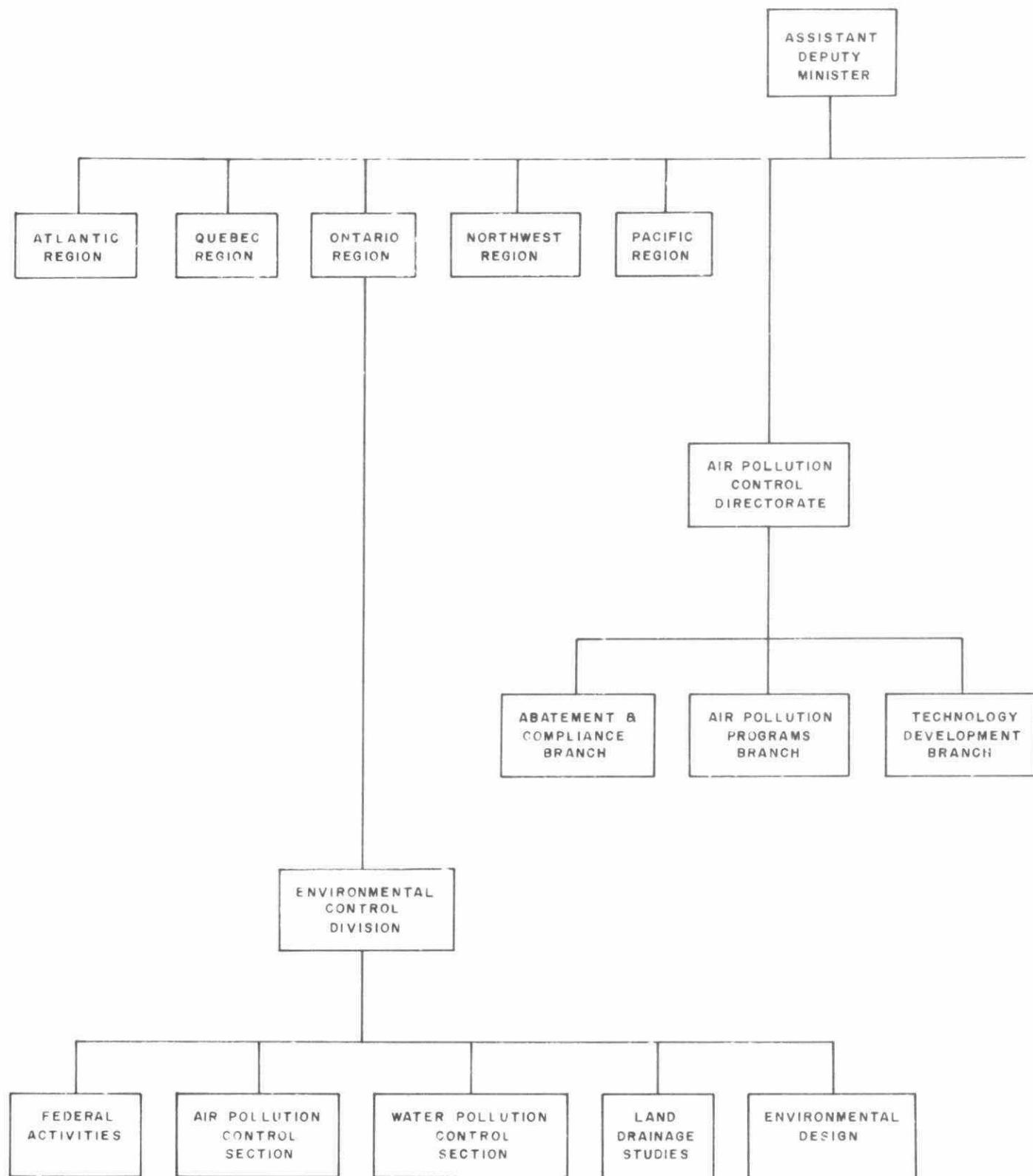
I. ORGANIZATION OF FEDERAL GOVERNMENT AIR POLLUTION CONTROL AGENCY

10.10 Responsibility for air pollution control is shared between the headquarters branch (Air Pollution Control Directorate) and the five regional offices (Figure 10-2). The headquarters organization is divided into three branches:

1. Abatement and Compliance Branch - responsible for the technical background leading to the formation and promulgation of Federal guidelines and regulations. This branch is organized on industry sector basis.
2. Air Pollution Programs Branch - responsible for the National Ambient Air Surveillance network, compilation of national air emission inventories, and final promulgation of emission guidelines and regulations.
3. Technology Development Branch - is responsible for the study of air pollution control technology, demonstration projects, administration of training courses and information retrieval. It is also responsible for laboratory services and motor vehicle test facilities. This branch also initiated a program to foster the development of new control technology through demonstration projects. The program (DPAT) operates on a shared-cost basis with the industrial sector.

The Regional Office is the contact with the Provinces and is responsible for liaison with Provincial Regulatory agencies in their areas with regard to federal guidelines and regulations, co-operative programs and, in addition, is responsible for the actual administration of federal regulations. Laboratory services and field support personnel are also centred in the National Capital Area District office in Ottawa.

ENVIRONMENTAL PROTECTION SERVICE



FEDERAL-PROVINCIAL ACCORD

10.11 An accord for the protection and enhancement of environmental quality was signed between the Ontario Ministry of the Environment and Environment Canada in October, 1975. Environment Ministries from Alberta, Saskatchewan, Manitoba, New Brunswick, Prince Edward Island and Nova Scotia are participating in this agreement also.

The accord calls for a broad framework which will enable the provincial and federal governments to work effectively together to identify potential environmental problems, find solutions and avoid duplication of effort.

The accord varies slightly between the provinces, but not in matters of substance. It extends for five years and provides for revision and renewal. Subsidiary agreements can be signed to cover particular environmental concerns.

Canada and the signing provinces have agreed to:

- Determine and establish desirable levels of baseline environmental quality.
- Develop national requirements and guidelines for pollution control by industry and municipalities.
- Consult on methods of monitoring environmental quality and exchanging assessment data.
- Implement pollution control programs.
- Develop contingency plans to deal with environmental emergencies, such as oil spills.
- Co-operate in research, exchange of technique, and staff training.

- Share costs for joint programs.

The agreement provides for the free and complete interchange of information and for the mutual adoption of objectives to the effect that goals adopted by one party would become goals of the other partner.

SUBJECT:

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

TOPIC: 11

METEOROLOGICAL ASPECTS AND
MEASUREMENT OF AIR POLLUTION

OBJECTIVES:

The trainee will be able to:

1. Describe briefly the two main ways in which the dispersion and dilution of contaminants takes place, and the relevant factors which assist or retard these processes;
2. Describe a temperature inversion and its possible effects on a large city;
3. Explain what is meant by the term "smog";
4. Explain what is meant by the term "photochemical smog".

Meteorology

11.1 Weather and climate influence to a great degree the level of air contaminants in the community. Unfavourable weather conditions permit a build-up of contaminants and, alternatively, dispersions tend to lower levels.

Dispersion and dilution of contaminants are activated by complex atmospheric forces such as the stability of the air mass, and the wind direction and velocity. Even when contaminant emission rates to the air are constant, concentrations at ground level may differ markedly from hour to hour with meteorological changes. The pollution emitted by the source may be dispersed in two ways:

1. Horizontally

11.2 Generally, the higher the wind speed, the greater the dispersion and the lower the ground concentrations. Direction is important in as much as the prevailing wind indicates the area of heaviest pollution in any city, e.g., East end as compared to West end.

2. Vertically

11.3 The temperature profile of the atmosphere determines the vertical dilution of contaminants.

11.4 Wind Speed is a particularly important factor as generally the lighter the wind the greater the concentration. This effect is very pronounced at a rate of 7 miles per hour or less. However, high winds are not

always beneficial as they can cause high pollution by aerodynamic down-wash of stack effluents, or prevent normal upward thermal rise of hot gases. The wind pattern of an area is extremely useful in determining the movement of contaminants.

11.5 Turbulence is another contingent factor and may be either mechanical or convective. The former is relatively small-scale in effect, being caused by obstructions to wind movement by buildings, hills and trees. The latter results from a regular heating and cooling of the land and air. The transfer of heat from the sun to the atmosphere is caused by radiative heating and cooling of the ground during the day, the conductive heating and cooling of the air layer in contact with the ground, and the convective transfer of heat by air movement. Warm air being less dense is displaced by cooler air and rises causing overturning and movement vertically. During stable conditions, when the temperature of an air mass is fairly uniform, turbulence is at a minimum. The relatively extensive air reservoir over any community is capable of accepting and dispersing large quantities of air contaminants without causing adverse effect. Problems arise when the air is still.

11.6 Ordinarily, temperature decreases with elevation above the earth. When the reverse occurs, a temperature inversion exists, resulting in stratification of the atmosphere. During an inversion, vertical mixing and turbulence are restricted, confining contaminants to a thin layer of the air mass near the ground. Resultant accumulations if prolonged for 5 or 6 days can be disastrous, as we discussed in our general introduction.

- 11.7 The change of temperature with height in the atmosphere is called the lapse rate of temperature.
- 11.8 The wind and lapse rate of temperature control the dispersion of a plume into the atmosphere.
- 11.9 Winds which vary their direction spread a plume out over a wide angle. (Figure 14-2)
- 11.10 Stronger winds dilute the plume faster.

11.11 Stronger winds also cause the plume to bend over into the horizontal faster and reduce the effective stack height.

11.12 The effective stack height is the distance from the ground to the level at which the centre of the plume becomes horizontal--the sum of the actual stack height and the plume's rise above the stack.

11.13 Factors that increase the plume rise and the effective stack height are the exit velocity of the plume from the stack and the difference in temperature between the plume and the air at the top of the stack.

11.14 The lapse rate of temperature determines the stability of the atmosphere. When the atmosphere is very stable the plumes spread out sideways and vertically very slowly. When the atmosphere is very unstable, the plume spreads out or disperses rapidly.

11.15 When the temperature decreases upward at about $1^{\circ}\text{C}/100$ metres, the atmosphere has neutral stability and the plume spreads out like a cone. This particular lapse rate of temperature is called the "dry adiabatic" lapse rate (Table 14-1)

11.16 If the temperature decreases with height at a much slower rate than the dry adiabatic rate or if the temperature stays the same with height or if it increases with height, the atmosphere is stable and the plume does not spread out vertically although it may "fan" out in the horizontal. (Figure 14-2 and Table 14-1)

11.17 If the temperature decreases with height at a greater rate than the dry adiabatic rate, the plume will "loop" upward and downward.

11.18 Temperature Change with Height

<u>Change with Height</u>	<u>Lapse Rate</u>	<u>Stability Type</u>
(a) Decreases at 1°C per 100 metres	Dry Adiabatic	Neutral
(b) Decreases faster than $1^{\circ}\text{C}/100$ metres	Superadiabatic	Unstable
(c) Decreases slower than $1^{\circ}\text{C}/100$ metres	Subadiabatic	Slightly stable
(d) No change with height	Isothermal	Stable
(e) Increases with height	Inversion	Very stable

11.19 The types of temperature inversions important in air pollution are the nocturnal or radiation inversion and the subsidence inversion.

11.20 The nocturnal inversion forms at night when the ground cools off by radiating its heat outward to space. How deep and strong this inversion is depends upon the wind speed and the rate of cooling of the surface.

11.21 The wind must be light (less than 5 mi./hr.) for an inversion to form. Strong winds will mix the air and maintain a temperature decrease with height. A lack of any wind will cause the inversion to be very shallow but very pronounced, since the exchange of heat between the air and the ground will be very slow.

11.22 The nocturnal inversion will not form or will be weak if the night-time sky is cloudy. The clouds will absorb the radiation and re-radiate it back to earth, keeping the air warm in the lower levels.

11.23 If the air is moist, a fog will form with the nocturnal inversion. It will not form with strong winds and if there is no wind, only dew or waist-high fog will form.

11.24 The depth of a radiation inversion grows as the night proceeds. It may reach 1500 to 2000 feet in depth. Thus, depending on circumstances, its top may or may not be higher than the height of a smoke plume.

11.25 In the morning, a radiation inversion is broken up by the heat of the sun which warms the ground. The heat is convected upward higher and higher into the air until it reaches the top of the inversion. During the process the inversion layer is elevated and does not extend to the ground.

11.26 The morning inversion breakup will change a fanning plume into a fumigation situation when the convective currents reach the height of the plume. The plume will be spread downward rapidly during a period of about half an hour during fumigation.

11.27 A subsidence inversion is an elevated inversion, the base of which is generally between 4000 and 6000 feet above the ground. It is formed when a layer of air slowly sinks and warms to a temperature higher than the air below.

11.28 Precipitation is also a cogent factor, reducing gases, wind blown dust and other suspended particulates from the atmosphere by the "scouring" action of rain and snow. Unfortunately, precipitation is undependable so far as frequency and amount are concerned. The proximity of the lakes to Ontario has a bearing on the amount of rainfall in this region. Winds off the lakes occur frequently in both summer and winter, influencing the frequency of rain and snow fall.

11.29 Cloud cover is a factor in air pollution levels, tending to increase stability in the lower layers of the atmosphere. Clouds reflect short wave solar radiation back into space at the same time absorbing long wave terrestrial radiation, modifying ground level temperatures. The lower and denser the cloud layer, the more moderate are temperature changes beneath it, with less air movement and cleaning effect. Usually only stratus clouds are associated with stable atmospheric conditions. A high percentage of cloudiness over a period of time allows a persistence of stratus conditions. Conversely, cloudless days produce thermal turbulence and aid large-scale diffusion of pollutants. The periods of greatest instability in this area occur during the summer months which have the least cloudiness. Cloudiness increases sharply in November, reaching a peak in January.

11.30 Fog is a manifestation of a number of factors. The atmosphere is made up of air masses of various extent which differ considerably in water vapour content and temperature. Some of the water vapour may be visible to the eye as cloud, but there is usually a vary large amount which is invisible, which we term "relative humidity". Generally speaking, the amount of water vapour which a

mass of air can hold depends on its temperature. It is possible in several ways for a particular air mass to be cooled to a point where it can no longer hold all its water vapour in an invisible state, and some of the vapour is condensed on the minute particles always present in the atmosphere, and it becomes visible. It may form a cloud above the surface of the earth, or it may appear at ground level as a mist or fog, or it may only show as drops of water on different surfaces. The temperature at about which this condensation takes place is called the "dewpoint".

As an example, a mass of comparatively dry air at a temperature of 16°C has at a particular moment a relative humidity of 50%, but if we drop the temperature to around 4°C , the air mass would become very damp air with a relatively high humidity of about 100%, and if we drop the temperature still lower some of the water vapour would condense and we would see mist falling.

All the clouds which we see in the sky and all the mist, or fog, which occurs on the earth surface, is formed by this cooling process, always excepting, of course, the man-made mists and clouds of smoke and dust.

On any clear calm night the earth will lose heat by radiation at its surface and the air in contact with it becomes cooled. If the cooling is sufficient to drop the temperature of the air below its dew point, fog may be formed; this is known as radiation fog. Fog is also formed when a comparatively warm and moist air-current spreads across frozen, or snow covered, ground. Cooling takes place in the air in contact with the cold surfaces and fog is formed.

11.31 Smog is a combination of smoke and fog. We mentioned earlier that fog can be caused by water vapour condensing on minute particles always present in the atmosphere. If a smoke haze of combustion aerosols is present in the atmosphere and the temperature falls below its dew point, the water vapour condenses on the aerosols forming smog.

The worst development occurs when conditions favour the development of smog when a temperature inversion exists. In these conditions the smog gathers on the surface of the earth, considerably reducing visibility, and rendering breathing difficult. Such were the conditions which gave rise to the terrible smogs in London, England.

Photochemical Smog

11.32 The Los Angeles type "smog" is not a true smog, since it does not contain smoke or fog. In Los Angeles, where gas and oil, rather than coal, are utilized, the smog is light in colour, consisting of solid and liquid aerosols in a fine state of subdivision, and numerous organic and inorganic gases. It also differs from true smog in that it does not occur at night; it results in intense eye irritation; and it causes characteristic damage to plants.

In this type of smog it has been found that there is a considerable increase in the concentrations of ozone and oxidant material in the atmosphere and the ozone is only found in daylight hours. All known facts indicate the photochemical formation of ozone or oxidant from impurities by the action of sunlight. The theory is that nitrogen dioxide absorbs ultraviolet light

and forms atomic oxygen and nitric oxide. Reaction of the products with molecular oxygen leads to the formation of ozone and the regeneration of nitrogen dioxide. The nitrogen dioxide is, therefore, available for repetition of the process, unless converted to nitric acid or used up in organic substitution reactions. Even low concentrations of nitrogen dioxide could produce relatively large amounts of atomic oxygen to form ozone or to react with organic pollutants to yield compounds which could cause eye irritation, crop damage, and reduced visibility.

In addition to the photochemical reaction between nitrogen dioxide and oxygen, photochemical side reactions take place between nitric oxide and hydrocarbons, particularly those in the unsaturated or olefin group, in which lachrymators (tear-causing compounds) are produced. This in turn produces more nitrogen dioxide and so more ozone.

The greatest source of hydrocarbons and oxides of nitrogen in Los Angeles (1 motor vehicle to every 2 inhabitants) is the automobile. Some hydrocarbons evaporate to the atmosphere from storage and automobile gasoline tanks; some escape during combustion as crank-case "blow-by" emissions; but the bulk of the emissions are through the exhaust pipe.

Weather Maps

11.33 A weather map will depict some or all of the following (Figure 11-1):

- (a) Lines of constant atmospheric pressure - "isobars"
- (b) Low pressure areas - "lows" or "cyclones"

- (c) High pressure areas - "highs" or "anticyclones"
- (d) Fronts
 - 1. Cold
 - 2. Warm
 - 3. Stationary

11.34 Fronts separate masses of cold and warm air. The warm air slants above the cold air with height. If the cold air is advancing, it is a cold front.

11.35 Generally, there is a high-pressure area shown in the warm- and in the cold-air masses. Also, the fronts are generally shown extending out of low-pressure areas; frequently, a low-pressure area has both a cold and a warm air front attached to it.

11.36 From day to day, generally, the fronts and pressure areas will move from west to east. The cold fronts may move southeast and the warm fronts northeast.

11.37 The highs and lows have the following distinguishing characteristics:

High-pressure area

- (a) Winds flow outward from a high in a clockwise direction
- (b) Air sinks creating a subsidence inversion
- (c) Low relative humidity, few clouds, little precipitation, sunny skies
- (d) Low wind speeds, variable wind direction
- (e) Nocturnal inversions likely
- (f) System covers a large area
- (g) System moves slowly and may remain stationary for several days.

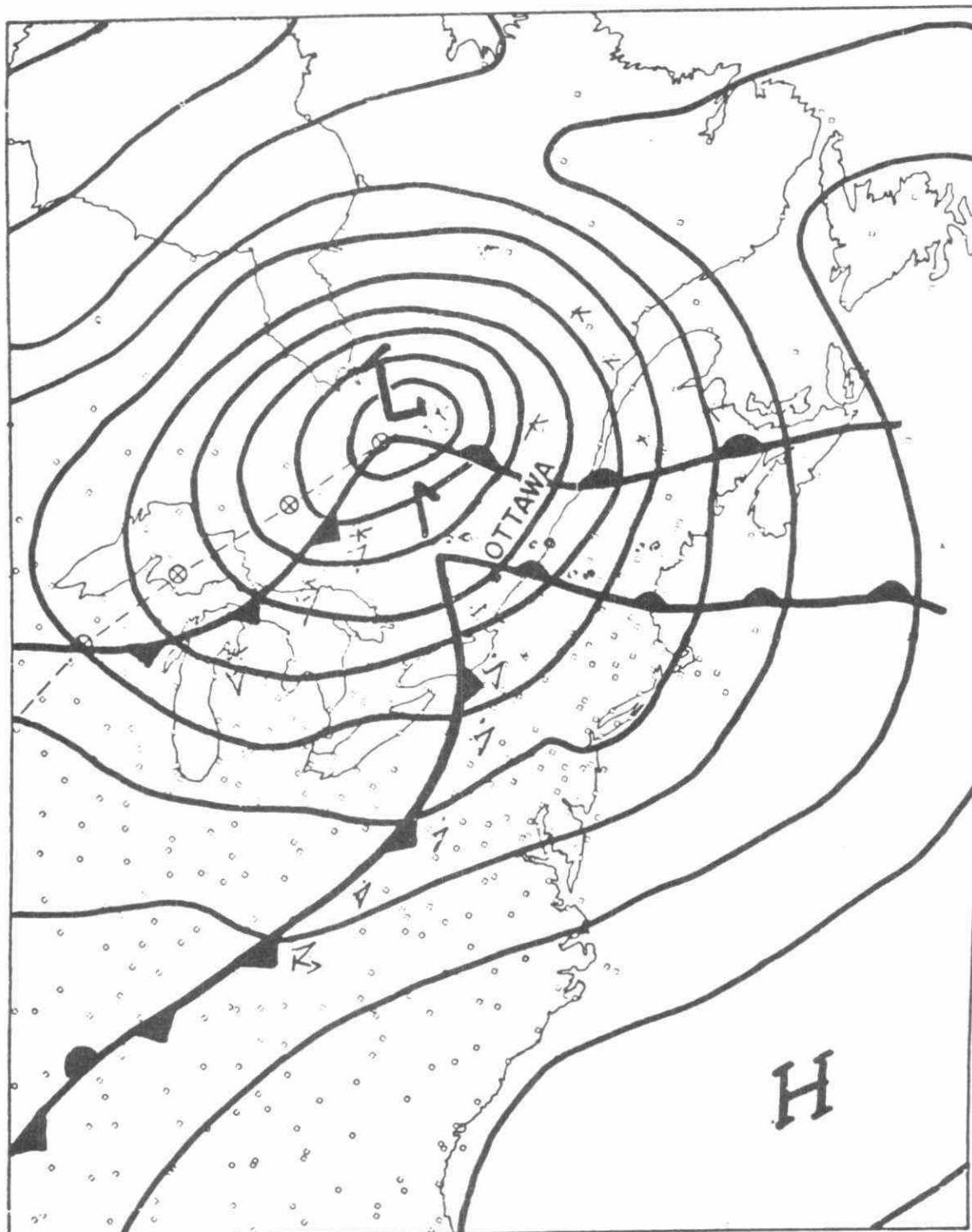


FIGURE II-1 SURFACE SYNOPTIC WEATHER MAP

Low-pressure area

- (a) Winds flow inward toward a low in a counterclockwise direction
- (b) Air rises giving good dispersion
- (c) High relative humidity, cloudy, precipitation likely
- (d) High winds likely
- (e) Inversion development unlikely
- (f) System covers small area
- (g) System moves rapidly

Useful Information that can be Obtained from the Daily Weather Map

11.38 The passage of fronts or low-pressure areas generally brings precipitation and strong winds. The precipitation will remove most of the particles from the air and improve the visibility. The strong winds will also clean out the air.

11.39 After a cold front passes the skies will generally become cloudless. Radiation inversions will form at nights causing fanning plumes in the mornings. The colder weather will produce denser and longer water plumes.

11.40 Near the centre of the high-pressure area the wind speeds will be low, the air will be hazy, and visibility will be poor. If the high remains stationary for several days, smog will increase, especially in the fall or summer.

11.41 The precipitation preceding a warm front is mostly of a steady type. That accompanying or preceding a cold front is of a showery type.

11.42 Wind direction generally is nearly parallel to the isobars, the lines of constant atmospheric pressure. If one stands with his back to the wind, the lower pressure will be on his left and the higher pressure will be on his right. (In the Southern Hemisphere this relationship is reversed.)

11.43 The weather along a stationary front could be rain, fog or snow, depending on the season.

11.44 Upper level winds (5,000' to 30,000') probably will not be in the same direction as the surface winds shown on the map. Upper level winds blowing over oceans, the Gulf of Mexico, or the Great Lakes may bring cloudiness inland. This will reduce the illumination and change the background for plume reading.

Ministry Weather Maps

11.45 The Air Quality and Meteorology Section of the Air Resources Branch issues each working day surface weather maps for the Province of Ontario. These maps are distributed for use by Ministry staff for the determination of wind conditions which may affect the air quality within Ontario. Information presented upon the maps may, however, be interpreted for other usage.

11.46 Data plotted on the weather map is received from the indicated stations by teletype using the hourly aviation weather format. A sample message and the resultant station plot is shown in Figure 11-2. In general, each station contains the following information:

1. Cloud cover
2. Wind speed and direction
3. Temperature
4. Present weather.
5. Visibility restrictions due to fog or haze, if present.

Definition of the symbols used are defined in Tables 11-1, 2 and 3.

11.47 In addition to station data, larger scale weather systems which affect the coverage area are plotted. These include frontal systems, pressure centres, and general air flow patterns. The symbols used to represent these elements are shown in Table 11-4.

11.48 Weather patterns may be interpreted using the following rules of thumb:

1. The protuberances on the frontal symbols indicate the direction that the front is moving.
2. Surface air flow patterns may not indicate the direction in which weather elements are moving.
3. Weather patterns generally move from SW to NE, W to E, and NW to SE.
4. The passage of a frontal system generally changes the character of the weather.
5. Warm fronts are generally characterized by rising temperatures, southerly component winds, low clouds and/or fog, and persistent precipitation.
6. Cold fronts are generally characterized by falling temperatures, westerly or northerly component winds, and showery forms of precipitation from convective clouds.
7. Stationary fronts are generally characterized by persistent conditions of wind, precipitation, and cloud cover (generally low). Stationary fronts may vacillate over an area bringing significant changes in the weather as the frontal line passes the station.

Air Quality

11.49 For air pollution to exist we must have a source emitting pollutants, air transporting the pollutants, and a receptor receiving the pollutants.

Figure 11-2

SAMPLE WEATHER MESSAGE AND PLOTTED STATION

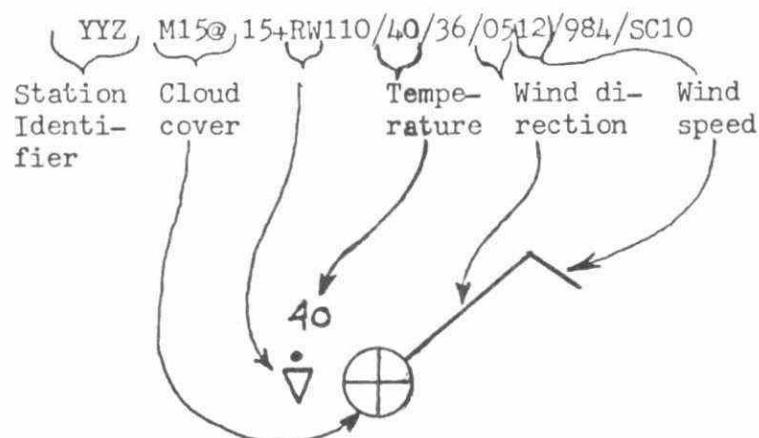


Table 11-1

CLOUD COVER

-  Clear
 -  Scattered
 -  Broken
 -  Overcast
 -  Obscured

Table 11-2

WIND SPEED AND DIRECTION

- A wind scale diagram consisting of six entries. Each entry features a small circle at the top left followed by a line segment. The length of the line segment increases with the wind speed. The entries are:

 - Calm: A short horizontal line segment.
 - 2 mph wind: A line segment extending slightly to the right.
 - 5 mph wind: A line segment extending further to the right.
 - 10 mph wind: A line segment extending even further to the right.
 - G25: A line segment ending in a vertical line that then turns 45 degrees upwards and to the right.
 - 15 mph wind with gusts to 25 mph: A line segment ending in a vertical line that then turns 45 degrees upwards and to the right, with the text "G25" written above it.

Each full barb represents 10 mph

Each half barb represents 5 mph

Wind direction - arrow points in direction wind is coming from.

Table 11-3

PRESENT WEATHER TYPE

	Haze		Fog patches
	Smoke		
	Fog and Visibility (Miles)		Blowing snow
,	Very light drizzle		Light drizzle
.	Very light rain		Drifting snow
..	Light rain		Heavy drifting snow
•	Moderate rain		Snow pellets
••	Heavy rain		Snow grains
*	Very light snow		Lightning
* *	Light snow		Squalls
* *	Moderate snow		Ice crystals
* *	Heavy snow		Heavy rain showers
*			Heavy snow showers
R.	Thundershowers		Heavy Thunderstorm
~	Freezing rain		
~	Freezing drizzle		
△	Hail		
△	Ice pellets (Sleet)		

Table 11-4

PLOTTED WEATHER SYSTEM SYMBOLS



Cold Front



Warm Front



Stationary Front

L

Low Pressure Front

H

High Pressure Center



Air Flow Pattern



Trough

11.50 From a physical standpoint, all pollution added to the air falls into three classes:

1. Dust fall
2. Aerosols
3. Gases

1. Dust Fall

11.51 This is the term to describe all particles of a certain size which do not stay suspended in the air, and tend to be deposited very near their origin. From the combustion of coal, these large particles could be fly-ash (mineral matter from completely burned coal), or grit (unburned or partly burned coal). From non-combustion processes, such as grinding, or road and building construction operations, mineral matter is disturbed and deposited near this type of activity. Generally speaking particles of sizes larger than 4 microns are deposited very near the source of emission.

2. Aerosols

11.52 Stokes' Law states that the velocity of free fall of small particles in still air is proportional to the square of the diameter. With a density of 1, the free fall for particles

50 microns diameter is 14.8 ft/min

20 microns diameter is 2.4 ft/min

10 microns diameter is 0.6 ft/min

For a particle 1 micron in size, the free fall is 5" per hour. If the density of the particle is 2, the free fall of the particle is twice the rate given above for the various particle sizes.

It should be noted that aerosols may be solid

or liquid. Liquid fumes (e.g. SO₃) are generally in the size range 0.1 to 1 micron, tobacco smoke and most smoke particles are less than 0.5 micron in diameter.

3. Gases

11.53 The behaviour of gases in the air depends on their density and the density is indirectly proportional to temperature. When gases such as SO₂ are emitted at high temperatures, the plume rise may be considerable before the gases cool to the ambient air temperature, thereafter they are subject to large scale atmospheric diffusion. The dilution and dispersion of gases and aerosols in the atmosphere are similar; the main difference is that on impaction on a solid surface, aerosols will be removed from the air where gases will not.

The Ministry of the Environment utilizes the latest designed instruments available in their air quality monitoring program, the method of sampling varying with the classes of air pollution we have just considered.

Sampling Methods

1. Dust Fall

11.54 In Ontario, the method used for collection is that laid down by the Air Pollution Control Association Committee. This collector consists of a plastic jar 6" in diameter and 12" or 18" long, a cross-sectional area of 28.27 square inches. The collectors are exposed for approximately 30 days. During this period they collect rain, snow and dust. In the summer high evaporation may cause the collectors to become dry, while in

winter they become frozen. Dust fall measurements are reported in tons/sq. mile/30days, or lb/1000 sq. ft./30 days.

Since the type of activity in the area will determine the amount collected, the type of activity within the area must be described. Such description would note whether the sample came from an industrial, commercial, or residential area, and location of the jar. This type of measurement is useful in locating gross pollution sources, and for indicating long term trends. An analysis would contain: water soluble solids; metal analyses; and microscopic examination of collected particulates.

The interpretation of the results will give a mean figure and is a useful measurement of the monthly, or yearly, dust fall.

2. Aerosols

11.55 The two most common methods used in Ontario for measuring the aerosols suspended in the air are:

(a) High-volume Sampler.

The original high-volume sampler consisted of the motor and blower of a cylinder-type vacuum cleaner, suitably enclosed and fitted with a holder for flat filter paper instead of a dust bag. Present versions are more refined, but little different in concept. Current samplers are generally exposed inside a case which places the filter surface horizontal, facing upward, under a roof which keeps out rain and snow, and generally prevents collection of particles larger than about 100 microns.

This air sampler draws a large amount of air, 55 to 70 c.f.m. for 24 hours through a fibreglass filter paper measuring 8" x 10". This paper is weighed before and after sampling, the difference in weight being the weight of aerosols collected, in approximately 2,000 cubic metres of air during a 24 hour period. The loading is reported in microgrammes per cubic metre of air. The criterion used for this type of sampling is 90 microgrammes per cubic metre per 24 hours. Readings above this figure indicate that some form of control is advisable. Detailed analysis can be carried out from the filter paper - chlorides, carcinogens, and radioactive fallout being measured. Trace amounts of metals, vanadium, silver, zinc, beryllium, etc., can also be found by analysis.

(b) Low-volume (A.I.S.I.) Sampler

This sampler operates continuously, drawing outside air through a roll of #3 Whatman paper at a flow rate of 15 c.f. per hour. Air is drawn through the paper for a selected time, usually one or two hours, and a new portion of tape is then automatically moved into position and sampling is resumed. Aerosols deposited on the paper form a "spot" stain which can be evaluated by measuring the reduction of light transmitted through the soiled paper as compared with clean paper. The unit of measurement is the Co-efficient of Haze - Coh/1,000 ft.

Because of the low flow rate the sample collected on the paper consists of fine aerosols that are smaller than 10 microns and can be carried into the lungs.

The Ontario criteria is 1.0 Coh for 24 hours.

3. Gases

11.56 Gases occur in the atmosphere in very small concentrations and require more refined sampling methods.

(a) SO_2 is the commonest gaseous pollutant, occurring as an end-product in the combustion of all fuels. Field measurements of sulphation are made by exposing porcelain or glass cylinders covered with tapestry cloth and coated with a thin paste of PbO_2 (lead dioxide). They are housed in special containers and located in the area under investigation for a month at a time. The reactive sulphur in the air combines with the lead dioxide to form PbSO_4 (lead sulphate). Re-agent and product are both insoluble, but the rate of reaction is affected by moisture, wind speed and particulates. The special container, therefore, is necessary to protect the re-agent from rain and snow. The container has louvred sides to allow free passage of air through the container.

By this method, the amount of reactive sulphur compounds in the air can be approximately estimated in the laboratory, and with several of these units around a source of SO_2 , qualitative results can be achieved to indicate the increase and decrease of emissions, the area most heavily polluted, and in some cases the chances of vegetation damage.

Where more precise information is required of the hourly concentrations and their variations, a continuous sulphur dioxide analyser is available for continuous readings, but this instrument requires attention by skilled instrument technicians.

(b) Fluorides may also be measured in the field by a technique similar to the sulphation candle. #4 Whatman paper dipped in a slurry of lime or calcium formate is wrapped around the porcelain cylinder and exposed in a screen for a period of a month in the area under survey. Chemical analysis indicates the approximate

level of fluoride contamination at the different sampling points. Gaseous fluoride measurements are also taken by specific gaseous fluoride analyses.

(i) Hydrogen sulphide can be measured by a volume instrument similar in operation to the continuous sulphur dioxide analyser.

(ii) Other gases can be measured using continuous recording instruments, such as ozone, nitric oxide, nitrogen dioxide and total nitrogen oxide, SO_2 , CO, and hydrocarbon meters. These are specialized units and require skilled attention.

The fluoride candle is useful as a semi-quantitative method for indicating the sources of fluoride (F) and if there is a problem in the area. Continuous fluoride analysers are required for accurate information on gaseous fluoride levels.

SUBJECT:

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

TOPIC: 12

AIR CONTAMINANT DEPOSITS
CAUSING DAMAGE AND STAINS

OBJECTIVES:

The trainee will be able to:

1. Briefly describe why a high percentage of sulphur dioxide in the atmosphere is harmful to surfaces and materials;
2. Explain the significance of high oxidant levels and its effect on rubber;
3. Describe the effects of fall-out of acid particulates on materials;
4. Name the two principal caustics in common use and describe the effects of the more significant one on materials;
5. State why the important pollution properties of paint droplets are the drying rate, the distance travelled, and the degree of surface tension;
6. Briefly describe the operation of the various types of paint spray booths, and the simple control measures necessary to maintain their efficiency;
7. Explain the importance of wind direction in tracing the source of liquid particulates;
8. List the basic information headings required in a major investigation of a liquid particulate problem:
 1. Frequency and time of day contamination takes place,
 2. Length of period of contamination,
 3. When contamination was first noticed,
 4. Prevailing wind patterns for the area.

AIR CONTAMINANT DEPOSITS CAUSING DAMAGE AND STAINS

12.1 Stains refer to the damaging or soiling of property resulting from the inter-action between air contaminants and the surfaces or surface coatings of materials. In complaint problems, typical stains include pitting, incrustation, etching, spotting, buckling, abrasion, corrosion and other forms of deterioration.

Stains generally result from the deposition of mist droplets or liquid particulates, usually of an acidic or caustic nature, although some solid particulates and aerosols may also exhibit staining or damaging properties. The type of problem found as a result of mists depends on the nature of the industrial economy and the climate, particularly with respect to sunlight and humidity. Humidity increases the rate of corrosion, as well as influencing mist production. Sunlight induces photochemical reactions and catalytic reactions leading to the formation of oxidants. A typical corrosive atmosphere found in our urban areas today is one which contains a high degree of sulphur dioxide. Sulphur dioxide in the atmosphere, as we have noted, readily converts to other aggressive substances. Hydrogen sulphide and sulphuric acid will attack lead-based paints leaving a brown to black discolouration. Sulphuric acid, also, will attack a variety of substances, including building materials such as carbonate-bearing stone, zinc gutters, canvas, copper wire and surface coatings.

12.2 Cracking of rubber is an indication of oxidant levels which normally are highest during the period from May to September; this is borne out by the effects package studies carried out in Ontario. Other parts

of these studies included the tarnishing of silver plates, damage to nylon fabrics, and corrosion measurements over different periods of time in steel and zinc plates.

12.3 Local problems resulting from liquid particulates tend to fall into two categories:

1. Acid and caustic stains causing some form of permanent damage to property
2. Spotting by paints, oil, greases or other materials which adhere to surfaces without necessarily damaging them and which can be removed.

1. Damage by Acids and Caustics

12.4 A frequent type of complaint encountered concerns the discolouration and damage of lead-based paints, particularly automobile finishes, by acids. Acid stains usually appear as brown-to-black irregular pin pricks to spots which range in size to approximately $\frac{1}{4}$ " in diameter, shaped in the cross-section of the depositing mist droplet. Cars so damaged exhibit a spotty appearance, particularly on the upper surfaces of the vehicle. In cases where acid deposits are found, the source is usually located close by. Virtually all acids in appropriate concentrations by their nature contain properties of a potentially damaging character. They will attack and discolour materials; dissolve or corrode metals, oxides and carbonates; burn or ulcerate skin; and irritate the eyes. Some acids like phosphoric acid, used in the production of fertilizers, ceramic and glass products, phosphoric anodizing, petroleum refining, catalysts, and cleaning of metals, are capable of

attacking canvas and aluminum sidings, and will cause incrustation on automobile finishes which, however, can be wiped off. Nitric and nitrous acids, which may be emitted as a brown cloud in by-product manufacturing or fertilizer processing, or explosives plants, may also give off irritating corrosive mists. Hydrochloric acid, which is emitted as a by-product in the manufacture of chlorine products; used in the manufacture of scale solvent; in making swimming pool acidic adjustments; in pickling processes, etc., will attack metal fencing and similar materials.

12.5 The three most important acid mists are chromic, sulphuric, and hydrofluoric acids. These acids are not usually emitted as a regular consequence of production cycles, but usually as a result of accident or equipment failure. Most plant operators, for reasons of health and safety, attempt to maintain careful control of acid handling. When control equipment fails, acid particles build up with moisture on control surfaces and are dumped or exhausted into the atmosphere under draught pressure.

Chromic Acid

12.6 In addition to attacking paint, chromic acid mists are also capable of causing eye irritation and offensive ("dead cat") odours. The primary source of chromic acid mist is inadequately controlled electrolytic chromium plating tanks. Chromic acid mist results from the fact that hydrogen and oxygen bubbles, released electrolytically, pick up particles of the acidified solution formed in the film on the surface of the tank. Generally speaking, such problems arise from hard chrome rather than soft (decorative) chrome plating operation,

since in the former greater current densities and higher bath temperatures are applied, thus creating more side reactions and increasing the rate of emission of liquid particulates. Typical solution compositions for both soft and hard chrome plating are 0.53 oz. of chromic acid per gallon solution. Typical current density and bath temperature for soft chrome are 115 amps. per sq. ft. and 40°C for hard chrome, 216 - 288 amps. per sq. ft. at 50°C. Such operations can be controlled by a commercial mist inhibitor or surface-active agent, which breaks up surface tension and keeps the particles which would ordinarily form a surface film in solution, or by the use of wet collection or dry-type filters.

Sulphuric Acid

12.7 Because sulphuric acid is one of the most economical of the inorganic acids, it is widely used in industrial operations to remove sulphur and unsaturated compounds, in battery manufacturing, for purification, and in many refinery and plating processes. Sulphuric acid mist droplets are capable of producing brown to black discolouration and pitting on lead-based surface coatings. Another familiar effect is the deposition of sulphuric acid either directly or indirectly in the troughs formed in the slack of canvas awnings. Sulphuric acid will destroy materials wherever it is permitted to accumulate.

Hydrofluoric Acid

12.8 Hydrofluoric acid readily fumes and is capable of severely attacking skin, poisoning leafy vegetables and flowers, and pitting glass and metal. It is used in the

commercial production of fluorides, in metallic aluminum and metal fluorides, insecticides and laundry products. It is prominently used in the etching, frosting and polishing of glass, and as a catalyst in the conversion of olefins and isoparaffins in alkylation plants in refineries, as well as in the pickling of steel alloys. It will distinguish itself from the other acids by causing comprehensive damage. When it attacks an automobile, for example, it attacks the paint, chrome and glass. Because of the high degree of activity of this contaminant, and its danger to health, equipment and vegetation, it is handled and controlled carefully by maintenance in a dry state or in such dilute quantities as to avoid causing damage in the vicinity of its use. Because of the interest in its control, hydrofluoric acid is more likely to create a one-time problem as a result of equipment breakdown, particularly from an alkylation plant, rather than a continuing chronic problem. It may also occur as a by-product in the manufacture of rocks and phosphate when sand used in its control is spent. (Hydrofluoric acid reacts with silica, or sand, to form hydrofluosilic acid.)

Caustics

12.9 Caustics fall into the chemical category of alkalies, that is, they are capable of neutralizing acids as well as providing a detergent, and, in some caustics, an etching action. Principal caustics are sodium carbonate and sodium hydroxide, the latter being more commonly used. Sodium carbonate is used in large scale chemical manufacturing, the manufacture of glass, soap powders and detergents. Of the caustics, sodium hydroxide is perhaps the most significant since it

attacks the skin, is strongly alkaline, and very soluble. It is employed in the petroleum industry, in the viscose process for rayon manufacturing, and the manufacturing of chemicals and soaps.

In sufficient concentrations it will attack paint, glass, and aluminum, and cause pitting, etching and buckling. The etching properties of this chemical are put to use in the aircraft industry in a chemical milling process which reduces the thickness of preformed, stress-relieved aircraft parts made of aluminum, magnesium, stainless steel and titanium. This chemical process performs milling jobs such as shaping and tapering, and can mill surfaces at the rate of 1/1000 inch per minute. The chem-mill bath consists of a caustic etching solution of 7% sodium hydroxide by weight, water, and a trace of sodium aluminate, and is heated to about 90°C. The sodium hydroxide mists are usually vented by means of slot hoods to a water scrubber. If uncontrolled, chem-milling may cause a problem.

2. Spotting by Paints and Other Materials

12.10 Complaints which have to be dealt with in this category result from the deposition of paint, oil, grease droplets or other materials which adhere to surfaces or surface coatings without necessarily damaging them. Quite often such deposits are readily removed with water, thinners, or detergents. In some cases, surfaces may require rebuffing and repainting. The droplets of this type are generally significantly larger or heavier than those described previously, and enter the atmosphere directly from spray or atomizing devices, and occasionally by entrainment and ejection from wet collection equipment or blower exhaust systems.

They frequently contribute to the contamination of automobiles, house sidings, clothing etc., in the community in which the spraying is performed.

Paint Spots

12.11 Paint spots are mist droplets of paint pigments and binders which deposit in a liquid state and adhere to surfaces. Paint mists are frequently emitted from paint spraying operations usually conducted under high-volume production conditions. With average wind movement and humidity, all paints tend to fall out within the first 150 to 500 feet from the source, with the exception of certain metallic pigmented paints, such as aluminum, which may travel as much as half a mile.

12.12 The important pollution properties of paint droplets are the drying rate, the distance travelled, and the degree of surface adhesion. The speed at which paints dry depends primarily on the rate of evaporation of the volatile portion (solvent) contained in the paint. Paints containing slow-drying solvents may travel in the air as mist droplets which then dry after deposition on surfaces. Paints which require heating or baking for drying are generally of this type. Baking enamel, for this reason, is often implicated in over-spray complaints. Primers, sealers and water-based paints, although emitted as a liquid are deposited as a solid, and have the appearance of coloured dust, depending on the relative distance between the source and the surface. Zinc chromate primer, for example, is yellow-green, while lead primer is red.

Paints also give off characteristic odours usually due to the evaporation of the organic solvents (varnishes or oils) contained in the vehicle of the paint. The principal vehicles used are oleoresinous varnishes, alkyds, dispersion resins, malamine, and phenolics. An odour problem from paint is generally not significant unless complaints are very close to the source.

12.13 The uses and relative pollution properties of commonly used paints are described in Table 12-1. Drying rates, it should be noted, vary considerably within any category of coating, depending on the initial drying or "flash off" of the specific solvents. Those shown in Table 12-1 are for typical industrial situations.

12.14 Complaints generally arise from the use of paints only when they are sprayed or atomized, usually with standard pressure spray guns. Paint spraying may be conducted in the open or in one of several types of specially conducted paint spray booths. "Open spraying" is conducted outdoors on structures so large that it is impractical or uneconomical to utilize a paint spray booth; for example, spraying of houses, structural steel beams, etc. However, most spraying, for reasons of economy and safety, and Fire and Health Department restrictions, are conducted within a suitably designed paint spray booth. The article to be coated is placed or mounted in the booth whether on a pedestal or conveyorized assembly unit, and is sprayed by an operator or automatic spray equipment.

12.15 The types of paint spraying operations employed depend on the nature of the material to be coated - wood, plastic, metal; the quality of the surface, i.e. smooth, rough, porous, etc.; and the quality of the surface coating desired, i.e. hardness, permanence, lustre, etc. Woodworking, metal fabrication plants, and automobile

TABLE 12-1

Relative Pollution Properties of Commonly Used Paints

<u>Coating</u>	<u>Use</u>	<u>Drying Rate</u>	<u>Removal</u>
Clear lacquer	Used for wood and metal finishing and as sealer	Fast, air drying.	Very light and volatile. May be removed with lacquer thinner.
Pigmented lacquer	For painting automobiles, or metal surfaces, for rapid drying (alkyd resin)	Fast, air drying	With lacquer thinner
Lacquer enamel	Same as above, but bake dried	Bake dry, slow air drying.	With lacquer thinner
Synthetic enamel	Automobiles, refrigerators, stoves, lighting fixtures, etc	Fast-slow air drying.	With lacquer thinner
Primer	Undercoating may use all types of resins and pigments such as red lead & zinc chromate.	Very fast drying	Usually dries to dust. May be easily rubbed off.
Clear Sealer	Non-pigmented primer	Fast to slow	Same as above, may be removed.
Water-based paint.	Emulsified with water; mannikins, papier-maché, houses, etc.	Very fast drying.	Same as above.
Metallic pigmented enamel	Painting large storage tanks, an economical protective coating.	Usually medium-slow, light, may travel long distances.	Aluminum-metallic paint adheres; may be removed with mineral spirits or thinner.

and aircraft manufacturing and repair plants are most generally encountered in air pollution problems, although paint spraying operations tend to be common to the entire industrial economy. Woodworking techniques include conditioning of the article by means of sanding, application of sealer, stain (either oil or water-based) and application of a final coat of lacquer. In plants manufacturing metal products, articles to be coated may be conditioned by degreasing with vapour solvents and buffering, and primers may be applied as undercoating. Lacquer-enamels, synthetic enamels or metallic pigmented enamels are applied as a finished coating. To improve the properties of adhesion, hardness and resistance to chemical deterioration, painted articles such as automobiles and other metal products are baked or force-dried in ovens at temperatures ranging from 65°C to 260°C.

12.16 In small plant operations, one booth may be used for application of preparatory and final coatings, whereas in large conveyorized assembly-line plants a paint spray booth may be utilized for each type of spray operation conducted.

The design of the booth, the equipment used, and the type and volume of paint sprayed affect directly the amount of air contaminants emitted. Booth design generally falls into two categories, dry and wet types.

12.17 The simplest dry-type booth is merely an enclosed structure equipped with a blower motor fan and stack. The size of the booth depends on the size of the object to be sprayed, and the blower motor and fan diameter are rated to handle the volumes of paint sprayed and the

dilution necessary to keep the air in the booth clear. The amount of paint mist entering the exhaust flow after spraying depends on the size and nature of the article being sprayed. A large flat article will retain most of the spray whereas smaller objects, or those which are gridded or perforated, result in greater overspray.

Although the walls and ceiling of the simple dry-type booth retain some of the overspray, most of the mists and vapours are drawn out through the blower systems to the outer atmosphere. Primarily used to balance the air flow, not to reduce emissions of these contaminants, flat metal panels, or baffles, are constructed as impact surfaces at approximately right angles to the air flow entering the outlet of the booth. Depending on the percentage of the cross-section of the exhaust outlet obstructed by the baffles, a proportion of the overspray is deposited and retained on the baffles.

12.18 A more advanced type of booth employs filters packed with a dry filter medium such as glass fibre, fine wire, metallic screening, or crimped paper. These are constructed in banks breeching the exhaust passages of the booth. The efficiency of such filtering media is relatively high for all paint particles, but not for solvents.

12.19 A more efficient design of booth is of the wet-type. This type is a special form of water scrubber constructed in the form of a recirculating waterfall curtain, which entrains the paint mist before it is exhausted to the outer atmosphere. The paint particles are then scrubbed out of the flow by detergent, are

collected in a settling tank, and the water recirculated. The more advanced of these booths are capable of collecting practically all types of liquid particulates, but some odours will be emitted (giving some indication of efficiency).

12.20 Known solvent recovery processes make some use of condensation, compression, absorption, distillation, or adsorption principles. Organic solvents used in coatings are not controllable by filters, baffles, or water curtains. In view of the small solvent vapour concentration in the airstream from the spray booth or applicator hood, the only economically feasible solvent control method is adsorption. Use of activated carbon has shown efficiencies of 90% or more to be possible, provided particulates are removed from the contaminated airstream by filtration before the airstream enters the carbon bed.

12.21 The effectiveness of the control features of all booths depends on proper operation and maintenance. Skilled operators attempt to reduce unnecessary overspray, not only to prevent air pollution but to conserve paint. Pressure guns are operated only when necessary, and with such skill as to accomplish an efficient and uniform coating of the article.

Booths utilizing dry-type filter media will require that filter media be changed or replaced whenever there is a significant drop in draught pressure. Agglomerated contaminants in neglected or overloaded filter media will be forced into the atmosphere by draught pressure. Wet booths require constant recirculation of water and the use of a suitable chemical detergent to keep the curtain flow clean. Periodic

cleaning of the booth is necessary to prevent stoppages in drainage and pumping systems which otherwise might result in exhausting portions of the contaminated solution into the atmosphere.

12.22 The design standards which must be met by paint spray booths are determined both by engineering calculation and empirically in the field. The amount of contaminants emitted into the air is readily determined from the estimate of overspray, production quantities of paints and thinners used, the scrubbing or filtering ratio, indraught and crossdraught velocities as well as the volume of air (cfm) moving through the control sections of the booth.

Other Materials

12.23 Other spotting, sometimes similar to acid or paint stains, can occur from a variety of industrial or non-industrial sources.

12.24 Oil droplets on property can occur from several sources - from malfunction at a refinery, high volume oil-quenching operations, and jet and other aircraft. Asphalt droplets may also occur from paving, roofing equipment, or asphalt saturators.

12.25 Another source of liquid particulates arises from the malfunctioning of collection equipment, particularly water scrubbers and wet filters, when particles entrained in the liquid media on wet walls, impact surfaces, or baffles are ejected into the atmosphere. This may occur accidentally from spray towers, roto-clones, and even electrostatic precipitators. Asphalt mists have been emitted from scrubbers and control equipment serving asphalt saturators.

Occasionally, mud-like particles are emitted from wet collectors serving sand conditioning equipment in foundries.

12.26 Some more unusual problems can be encountered from natural sources, such as spots on houses and cars resulting from bee droppings. These have a characteristic light to dark yellow, orange or brown appearance, round or oval on horizontal surfaces, or streaks on vertical surfaces, with a waxy consistency when fresh. On aging, these spots become dark grey-green or dark brown in colour, are brittle and easily removed from a surface by scraping with a fingernail. They can be washed off with water, though not water soluble. As car surfaces, for example, frequently appear peppered with spots, these spots are often mistaken for stains resulting from industrial equipment.

12.27 Another type of complaint which arises at infrequent intervals describes small colourless sticky spots on property surfaces, usually the upper surfaces of automobiles. Investigation usually reveals that the car has been parked under a tree for some time. The deposits on the surface are the droppings from certain aphids which feed on the leaves of the trees.

Tracking Liquid Particulates

12.28 Because air-borne liquid particulates do not travel nearly as far as do odours, they will generally settle out in the neighbourhood close to the source of the mist. This particular property of liquid particulates, taken together with the fact that they can be sampled, is of great assistance in tracking down sources since sampling equipment or test panels can be used.

When the source is unknown, an estimation of wind direction may be required. This may be accomplished by a study of paths of deposition. If one side of an automobile or a house is habitually contaminated, the wind direction may be inferred. The interview with the complainant should attempt to establish, if possible, the wind direction at the time of contamination. If this is impossible, the inspector should attempt to establish the time the contamination took place, so that he can inspect the premises to determine wind patterns for himself. In complex cases involving heavily industrialized communities with many possible sources, or where contamination does not appear to be localized according to wind direction, the inspector should plot a wind rose showing the direction from which the wind came, the time intervals, and the relative intensity. This information can then be used to plan reinspections and to determine the possible location of test panels should they be required.

Most sources of liquid particulates can be located by downwind tracing of the trail of fallout, or areas of contamination. If the contaminant has been identified, a given source may be shown to exist if the contaminated area is within the probable range of travel or fallout of the air contaminant; if the air contaminant is observed or detected emitting from the source in such quantities as to make contamination in the affected area probable; and if no other sources can be accounted for.

12.29 Once a plant is suspected, roof areas adjacent to stacks and vents should be observed for stains, coating, and other deposits which have accumulated. The extent of the damage, and the degree of deterioration,

decay, erosion, and general filth on the deposited material, should be compared with the total time the equipment or process has been in use, and that compared, if possible, with the extent of recent damage. The over-riding path of such deposition should also indicate the general direction contaminants have travelled in the atmosphere, and may be lined up with the complaint area in the community.

12.30 If no specific source is suspected, or more than one source is possible, a major investigation may be required, particularly if the damage from contaminants is serious and widespread. It is necessary to determine the boundaries of the damage in order to establish the range of travel. Once that is established, inspections of industrial facilities can be concentrated in the suspected area. The following should be determined from observation, testing and interview:

1. Frequency and time of day contamination takes place
2. Length of period of contamination
3. When contamination was first noticed
4. Prevailing wind patterns for the area

12.31 In complex cases a sketch or map should be drawn including the above information and indicating:

1. All possible plants, equipment and their distances from contaminated area
2. All areas affected, with notation as to which areas are most frequently affected, and their distances and directions from suspected sources

3. Pertinent addresses, such as point observations and complaints
4. Location of test panel or fallout jar stations

12.32 When fallout jars or test panels are necessary, they may be posted or stationed in the following manner:

- (a) On or near contaminated objects, such as automobiles or house sidings
- (b) If necessary in 360° circle around contaminated area to determine the path or trajectory of the contaminant, unless an inspection of the contaminated area already discloses the general pattern of disposition
- (c) Posting of one or more panels horizontally or stationing fallout jars as an indication of general fallout since some contaminants may travel long distances
- (d) Posting panels or stationing jars in possible lines of travel of contaminants from possible sources
- (e) Panels or jars should be systematically numbered and show dates of exposure. Exposure may be expressed in terms of hours, minutes, or days
- (f) Panels and fallout jars should be stationed and removed in a manner which will show time of day contamination takes place. The pattern for change may be based on a study of wind movement for the area

Solid Deposits

12.33 By deposits we refer specifically to particles of solid materials which settle out of the atmosphere or impact on surfaces. These are fine materials which are substantially in excess of one micron in diameter and have a relatively fast settling rate, such as dust, ash, minerals, grains, powders, flour, etc., and are large enough to be seen with the naked eye. Small invisible particulates do not generally enter into complaints, unless they react chemically with surfaces to form visible stains, abrasions or pittings. Complaints made against deposits concern the littering, soiling qualities of deposits, and the time and the expense required to keep property free of them. Deposits may also contaminate material such as clothing and nylon stockings, or enter into commercial or industrial processes as impurities. For this reason one industrial plant might complain of another about the contamination of its product by dusts or solid particles. Complaints are received concerning the chronic contamination of swimming pools from fly-ash or soot from incinerators or boiler plant located nearby. Such deposits frequently collect in rain gutters, window sills, sidewalks, porches, curtains or clothes.

12.34 The sources of solid deposits are extremely numerous. Dust is created by almost every commercial, domestic and industrial activity. Dusts are produced wherever materials are ground, pulverized, crushed, destroyed, scraped, milled, conveyed, etc. Deposits entering into significant complaints, however, most likely originate from the "dusty" industries, i.e., wherever dusts, grains, minerals and other solid particles are either manufactured or handled in large

volumes, or evolve as production waste. The "dusty" industries include grain and feed mills, mineral processors, fertilizer plants, pottery and ceramic manufacturing, hot asphalt and concrete batch plants, cement manufacturers, the roofing industry (mica, talc and crushed rock), woodworking industries (sawdust) and others. Handling and production equipment found in these industries include hammermills, pulverizers, crushers, bagging machines, shaking, classifying and grading devices, batching equipment, bucket elevators, air conveyor systems, aggregate driers, loading hoppers and scales, sanding equipment, shot blast booths, etc.

12.35 Even when control devices are installed, dust emissions may arise from leaks in equipment and conveyor systems, which should be checked for emissions. When a complaint is registered against a dusty industry, the officer should make an inventory of all the equipment, and make a flow chart to check out all possible points of dust emission.

12.36 The methods employed for tracking solid particulates from unknown sources are the same as those applied to liquid particulates. Solid particulates, however, are more readily traceable due to the trails, drifts or piles they tend to leave on the ground.

Where no immediate source is apparent in the community, it may be necessary to look for large sources located at considerable distances from complainants, such as steam-generating plants, ships, industrial incinerators, etc., especially when such dusts can be carried by strong prevailing winds, usually incoming shore breezes. A study of the micro-meteorology of the area will help locate a probable source area.

SUBJECT:

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

TOPIC: 13

ODOURS

OBJECTIVES:

The trainee will be able to:

1. Define "odour";
2. List the items an officer is concerned with in investigating an odour problem:
 1. Identifying and rating the intensity of the odour,
 2. Identifying the contaminant (odorant) causing the odour,
 3. Locating the "odour route",
 4. Locating the source of the odorant,
 5. Influencing some operational or engineering control over the odorant;
3. List the characteristics of odour perception which may be useful in estimating whether an odour problem exists;
4. List the three values used in evaluating odour:
 1. Quality
 2. Intensity
 3. Pervasiveness.

ODOURS

13.1 The interesting fact about odours is the enormous ability of humans to respond to thousands of distinct odour stimuli, and to detect contaminants which may originate from sources at relatively great distances. Odours can be detected in concentrations of gaseous materials as low as 1 part per billion parts of air. For this reason the nose has often been characterized as one of the best known devices for gas analysis. At the same time, the average person appears to lack the necessary vocabulary to describe odours.

13.2 A major difficulty in measuring odours is that although an odour is by legal definition an air contaminant it is essentially only an effect of an air contaminant on humans. To be more precise, it is a sense perception conveyed to the brain by nerve endings and sensory cells in the nose. Like all sense perceptions, intensity of sensation depends not only on the intensity of the stimulus but on the sensitivity of the percipient. For this reason the capacity in humans to perceive odours varies considerably, and in the same person from time to time. Some individuals are very insensitive to odours (anosmics) while others are acutely sensitive to odours unnoticed by most people. This fact complicates any estimate of the prevalence of an odour problem.

13.3 Odour has been defined as "the property of a substance or substances that is perceived, by inhalation in the nasal or oral cavity; that makes an impression upon the olfactory area of the body, and that, during and as a result of such inhalation, is distinct from seeing, hearing, tasting, and feeling and does not cause or result in choking, irritation, cooling, warmth, drying, wetting and other functions foreign to the olfactory area".

13.4 This definition is of practical use as it distinguishes between many sensations which may be confused with odour. The officer is concerned with:

1. Identifying and rating the intensity of an odour
2. Identifying the contaminant (odorant) causing the odour
3. Locating the "odour route"
4. Locating the source of the odorant
5. Influencing some operational or engineering control over the odorant

Characteristics

13.5 The following characteristics of odour perception may be useful in estimating whether an odour problem exists:

1. The olfactory sense becomes fatigued after continuous perception of an odour.
2. The sensation of odour is usually detected whenever there has been a significant change in odour quality or intensity. A pleasant odour can become objectionable to one who has become used to it under continuous exposure, but increased odour intensity.
3. Odours do not, in themselves, cause physical disease, but the odour of many toxic materials may serve as a warning agent.
4. The ability to perceive odours varies from day to day with the same person.

5. Compounds of different constitution may yield similar odours, whereas compounds of very similar constitution may yield different odours.
6. An unfamiliar odour is more likely to cause complaint than a familiar one.
7. The perception level of odours decreases with increasing humidity. High humidity tends, however, to concentrate odours within certain localities.
8. Odour quality may change on dilution.
9. Some persons are capable of sensing certain odour qualities, but not others.

Odorants and Their Source

13.6 It is not necessary for abatement purposes to consider all of the odorants. Nearly all substances known, excepting those to which one is accustomed such as oxygen, have an odour. It has been said that potent odorants generally possess a significant degree of volatility and chemical reactivity such as are exhibited by the aldehydes and various classes of hydrocarbons. Also, materials of high vapour pressure tend to yield odours more readily than those of low vapour pressure.

13.7 The average person would find all familiar environmental odours objectionable were they strong enough. There is no problem about identifying these through mental association. Such familiar odours as coffee, gasoline, moth balls, roses, tobacco, wood smoke, jasmine, paint, skunk, do not need further definition to most people and can be termed characteristic odours.

13.8 However, there are many odours whose qualities are familiar though the odorants themselves are not. These are the so-called chemical odours, as complainants might call them, associated with chemical and petrochemical processes. The odours of skunk, garlic, onions and cabbage, for example, may arise from various sulphur compounds, ethyl, methyl, propyl and butyl mercaptans, respectively, generated from oil-refining processes. These are good examples of the fact that compounds of different constitution have similar or analogous odours.

13.9 We may further distinguish between strong, pungent chemical odours, which offend primarily because of intensity, and those which are obnoxious or malodorous because of their quality. It is the latter type that causes most complaints. These tend to be odours originating from the handling and processing of organic compounds containing nitrogen and sulphur. The odours arising from nitrogenous compounds may be associated with animal odours and decomposition of animal tissue. The odours arising from sulphur are characterized by "rotten egg", "skunk", "decayed cabbage", as well as the acrid, bitter sulphide odours found in metallurgical operations. (Elementary sulphur and nitrogen do not exhibit odours.)

13.10 The introduction of nitrogen compounds tends to imbue substances with objectional animal odours. Amines, in particular, can have ammoniacal, "fishy" or decayed flesh odours. In the decomposition products of protein, such as occur in the animal rendering industry, mostly nitrogenous and sulphurous compounds may be involved. These also contain hydrogen sulphide, putrescine, cadaverine, skatole, and butyric acid. Other odorous compounds not involving nitrogen include phenols and cresols, employed principally in the manufacture of

resins, plastics, disinfectants, inhibitors, and agricultural chemicals.

13.11 There is fair agreement as to which activities produce obnoxious odours. Table 13-1 compiled by the Air Pollution Control Association, shows the type of odours most frequently reported by City Bureaus. The list here is fairly typical for most industrial economies, although the importance may change from community to community.

Rendering Operations

13.12 Because of its universal contribution to odour problems, the animal rendering problem deserves special mention.

Animal rendering consists of reducing to solids, fats and water, animal tissues from inedible meat and bone scrap derived either from slaughter-house remnants, or offal from poultry, dogs, cats, or other animal carcasses picked up from the streets. When the rendering operation is conducted in a slaughter-house or meat packing plant it is termed "captive" or "live" rendering. Independent renderers, on the other hand, comprise the animal by-product industry and may be mostly concerned with rendering the carcasses of animals salvaged from the streets. The products generally produced are tallow, grease, fertilizer, and animal feed. The processing of whole blood in a liquid form in slaughter-houses or captive rendering operations yields solid blood meal which is also valuable as fertilizer and in the manufacture of glue.

Table 13-1
List of Odours Most Frequently Reported by City Bureaus

Animal Odours

- 1) Meat packing and rendering plants
- 2) Fish-oil odours from manufacturing plants
- 3) Poultry ranches and processing.

Odours from Combustion Processes

- 1) Gasoline and diesel engine exhaust
- 2) Coke-oven and coal-gas odours (steel mills)
- 3) Maladjusted heating systems.

Odours from Food Processes

- 1) Coffee roasting
- 2) Restaurant odours
- 3) Bakeries.

Paint and Related Industries

- 1) Mfg. of paint, lacquer, and varnish
- 2) Paint spraying
- 3) Commercial solvents.

General Chemical Odours

- 1) Hydrogen sulphide
- 2) Sulphur dioxide
- 3) Ammonia.

General Industrial Odours

- 1) Burning rubber from smelting & debonding
- 2) Odours from dry-cleaning shops
- 3) Fertilizer plants
- 4) Asphalt odours - roofing and street paving
- 5) Asphalt odours - manufacturing
- 6) Plastic Manufacturing.

Foundry Odours

- 1) Coke-oven odours
- 2) Heat treating, oil quenching, and pickling
- 3) Smelting.

Odours from Combustible Waste

- 1) Home incinerators and backyard trash fires
- 2) City incinerators burning garbage
- 3) Open-dump fires.

Refinery Odours

- 1) Mercaptans
- 2) Crude oil and gasoline odours
- 3) Sulphur.

Odours from Decomposition of Waste

- 1) Putrefaction and oxidation - organic acids
- 2) Organic nitrogen compounds - decomposition of protein
Above odours are probably related to meat processing plants
- 3) Decomposition of lignite (plant cells).

Sewage Odours

- 1) City sewers carrying industrial waste
- 2) Sewage treatment plants.

13.13 Fish wastes in the cannery industry are similarly rendered to yield such by-products as fish meal, fish oil and high vitamin content residue. The odours in the case of fish reduction in canneries differ somewhat from the rendering plants described above, and are readily identified by complainants.

13.14 Rendering plant odours arise from two sources:

1. General housekeeping - the decomposition of animal tissue and offal in transit or storage prior to processing.
2. Vapour emissions from improperly controlled rendering equipment.

Odours from the former are generally sharper than those from vapour emissions, which are drier and mustier in quality.

13.15 A primary source of housekeeping odours results from the natural bacterial decomposition beginning at the death of animal tissue, which produces powerful odorants whose potency increases with time and temperature. These factors are greatly responsible for obnoxious odours arising from offal whose rendering has been delayed by transportation and handling. The arrival and then storage of offal may be sufficient to create an odour nuisance before processing. Moreover, some organs such as the stomachs and intestines are more odorous in themselves. Captive renderers, on the other hand, are not subject to this problem to the same extent as the independents, since the material to be rendered is freshly acquired from the slaughter-house.

13.16 Housekeeping odours also result from spillage, improper cleaning of plant floors, and storage in the open while awaiting rendering. The handling of materials in 55 gallon drums, which are not properly cleaned after use, alone can create strong odours. This also applies to captive rendering plants when processing is delayed by week-end or holiday shut downs. Monday mornings, for instance, are considered the most odorous periods in the vicinity of animal reduction plants, due to decomposed cooker feed-stock left from the previous week.

The problem of housekeeping maintenance at these plants is complicated by the fact that operators may either be anosmiacs or suffer from chronic odour fatigue. To control such odours greater cleanliness and sanitation in the plants are required.

13.17 The second source of odours arise from vapour emissions to the atmosphere from improperly controlled process equipment. Equipment involved consists mostly of boilers, driers, blood spray driers, crackling bins, rendering kettles, mixers, holding tanks, storage tanks, incinerators, and "catch basins". The most important part of the rendering operation is the cooking or dehydrating of the animal materials in steam-jacketed cooking vessels at temperatures generally exceeding 200° F. The cooker effluent contains mostly steam driven from the animal tissue - about 99% water. The material cooked generally varies between 35% to 50% moisture. The fat bone scrap is lower in moisture content than meat, and results in less vapour. The remaining 1% in the effluent consists of the odorous proteins and fats, hydrocarbons, and hydrocarbon derivatives - hydrogen sulphide, skatole,

putrescine, and cadaverine. These materials may not only be highly odorous as discharged but may break down on contact with air or sunlight to form even more potent odorants.

Odours from rendering vapours may travel considerable distances and are responsible for most of the complaints from communities near neighbouring rendering plants.

Other Odours

13.18 Other odours commonly experienced are hydrogen sulphide emissions (rotten eggs), mercaptans (garlic and skunk odours) and "sour gases" from petroleum operations (dead cat odours); aluminum oxides from slag or dross piles; decayed organic matter from dumps; coffee roasting; paint, lacquer and varnish odours.

Description and Measurement

13.19 Whenever an officer investigates odour complaints and attempts to establish the existence of an air pollution source, he must identify the odour and the odorant, describe its characteristics in terms of delineating the objectionability of the odour, and provide some notion as to its severity. In making such an evaluation the following values are used:

1. Quality
2. Intensity
3. Pervasiveness

1. Quality

13.20 Quality describes the characteristics of odours either in terms of association with a familiar odorant, such as coffee, onions, etc., (characteristic odours), or by associating a familiar odour with an unfamiliar odorant, by analogy. Aside from such direct descriptive terms, the observer, in an attempt to be complete and accurate, may add modifiers to his description to indicate overtones to the body of an odour. These may include subjective reactions such as "fragrant", "foul", "nauseating", or characteristics of odour which may be associated with the sense of taste such as "bitter", "sweet", "sour", "burnt", or even, partially with the sense of touch as far as contaminants which are irritating are concerned, such as "pungent", "acrid", "acidic", "stinging". A contaminant may sometimes affect more than one sense; an irritant can affect the sense of smell, cause eye irritation, and be tasted.

13.21 One system of odour classification is based on six types as follows:

1. Spicy - conspicuous in cloves, cinnamon, nutmeg, etc.
2. Flowery - conspicuous in heliotrope, jasmine, etc.
3. Fruity - conspicuous in apple, orange oil, vinegar, etc.
4. Resinous - conspicuous in coniferous oils and turpentine.

5. Foul - conspicuous in hydrogen sulphide and products of decay.
6. Burnt - conspicuous in tarry and scorched substances.

Table 13-2 lists certain pollutants with suggested descriptive odours.

2. Intensity

13.22 Intensity is some numerical or verbal indication of the strength of an odour. Intensity may remain constant, vary or fluctuate depending on air/odorant dilution rates. A gradual increase in intensity is readily detected, although persons may have become fatigued by the odour. A sudden increase in odour intensity, however, such as might be encountered by suddenly opening a flask containing ammonia or chlorine in a room has an intensity which may be characterized by an impact. Thus, an intensity has shock value, particularly in relation to pungent or putrid odours.

Experimental findings on the discernment of odour intensity are still incomplete, but the average observer or complainant can be expected to distinguish between three intensities, weak, medium and strong, whereas the expert should be able to distinguish between the five degrees of intensity shown below and the various categories of odour quality.

13.23 The intensity of the odour may be noted as follows:

0 - A concentration of an odorant which produces no sensation.

Table 13-2
Suggested Odour Descriptors

<u>POLLUTANT OR SOURCE</u>	<u>DESCRIPTOR</u>
1. Acetaldehyde	Fruity
2. Acetic Acid	Vinegar
3. Acetone	Nail Polish Remover
4. Acetylene	Garlic
5. Acrolein	Hot fats
6. African Fibre	Musty, sour
7. Allyl Mercaptan	Garlic
8. Allyl Disulphide	Garlic
9. Apiole	Parsley
10. Banana oil	Nail Polish Remover
11. Burnt protein	Burnt toast
12. Butyric acid	Scorched grain
13. Cannery waste	Rancid, perspiration
14. Carbon disulphide	Rotten eggs
15. Carbon tetrachloride	Rotten eggs
16. Cresol	Cleaning Fluid
17. Diacetyl	Creosote
18. Dimethylamine	Sweet butter
19. Dimethyl sulphide	Fishy
20. Enamel coatings	Decayed cabbage
21. Ethyl Mercaptan	Fatty, linseed oils
22. Ethyl selenide	Rotten cabbage
23. Ethyl selenomercaptan	Putrid, nauseating
24. Ethyl sulphide	Foul, foetid
25. Fatty acids	Foul, garlic
26. Fermentation	Grease, lard
27. Foam rubber curing	Yeast
28. Hydrogen selenide	Sour, sulphides
29. Hydrogen sulphide	Putrid
30. Indole	Rotten eggs
31. Iodoform	Faecal
32. Ionone	Antiseptic, iodine
33. Methyl mercaptan	Violets
34. Methylethyl ketone	Decayed cabbage
35. Oils: castor, coconut soya, linseed	Nail Polish Remover
36. Phenolic	Rancid grease
37. Phenolic resins	Carbolic acid
38. Pyridine	Carbolic acid
39. Septic sewage	Arid, goaty
40. Skatole	Rotten eggs
41. Sludge drying	Faecal
42. Sulphur dioxide	Burnt grain
43. Trimethylamine	Pungent
44. Valeric acid	Fishy-ammoniacal
45. Vanillin	Unclean body odour
	Sweet, aromatic

- 1 - Concentration which is just detectable (the threshold dilution).
- 2 - A distinct and definite odour whose unpleasant characteristics are revealed or foreshadowed (the recognition threshold).
- 3 - An odour strong and objectionable enough to cause a person to attempt to avoid it, after a period of exposure.
- 4 - An odour so powerful as to be offensive and repulsive and bordering on being intolerable.
- 5 - An overpowering, nauseating, intolerable odour.

3. Pervasiveness

13.24 Pervasiveness is sometimes referred to as odour potential or threshold dilution ratios. These essentially are a measure of the ability of an odour to pervade a large volume of dilution air and continue to possess a detectable intensity.

A pervasive odour such as might result from mercaptans and decomposed proteins will tend to spread in all directions over a community. An officer notes and records when tracking or establishing odour routes the general pervasiveness of odours. Such notations indicate the continuity and range of the odorant.

Tracking Odours

13.25 In many odour problems tracking is unnecessary. An experienced officer is often able to identify the source of an odour by its quality and intensity

and may be able to relate the odour to a specific activity. Since officers are familiar with the industrial establishments in their particular district, they are often able to connect the odour with a specific piece of equipment. The officer verifies his findings by following a definite odour route in order to prove that the odour emanates from a specific piece of equipment. In such situations it is not necessary to rate odours numerically but to describe the odours as they are perceived. In these cases the officer either follows the odour from the suspected source as it moves downwind to affected areas, or he proceeds from an affected area (i.e. from the complainants themselves) upwind to the source. The first method is for verification, the second for tracking an unknown source.

13.26 The consensus of odour quality in the complaint area must be identical to the odour quality emanating from the source. With the exception of "intensity" all significant point observations should agree. The intensity should vary in a geographical pattern. A point observation here is a stationary location at which an evaluation was made of the following:

1. Odour quality and intensity
2. Wind direction (Figure 13-1 and strength (Table 13-3) at time of odour
3. Duration of odour
4. Time of day and date

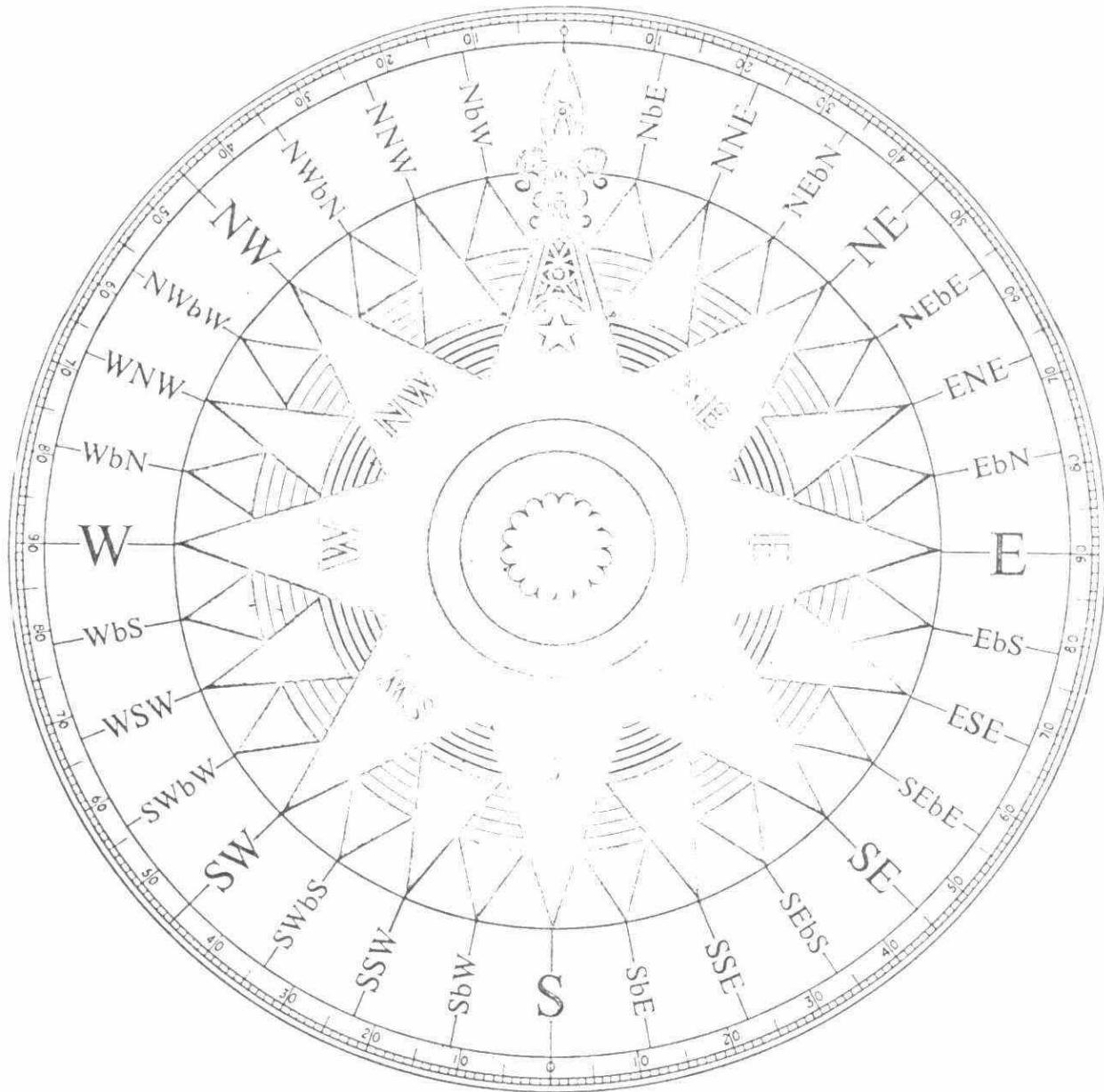


Figure 13-1

TABLE 13-3

BEAUFORT SCALE OF WIND FORCE

<u>Beaufort Number</u>	<u>General Description</u>	<u>Specifications for Estimating Velocities</u>	<u>Wind speed in m.p.h. at 33 ft. (10m.) above ground</u>
0	Calm	Smoke rises vertically	Less than 1
1	Light air	Smoke, but not wind vanes, shows direction of wind	1-3
2	Light Breeze	Wind felt on face; leaves rustle; wind vanes moved	4-7
3	Gentle Breeze	Leaves & small twigs moving constantly; small flags extended.	8-12
4	Moderate Breeze	Dust and loose paper raised; small branches moved	13-18
5	Fresh Breeze	Small leafy trees swayed	19-24
6	Strong Breeze	Large branches in motion; whistling heard in telegraph wires	25-31
7	Near gale	Whole trees in motion	32-38
8	Gale	Breaks twigs off trees	39-46
9	Strong gale	Slight structural damage occurs	47-54
10	Storm	Trees uprooted, considerable structural damage	55-63
11	Violent storm	Very rare; widespread damage	64-72
12	Hurricane	Very rare	Above 72

13.27 Each complaint represents a point of observation. Either the officer verifies the complainant's information, or, if there are so many complainants that he cannot do so, he requests the complainant to keep a record of this information. The pattern of complaints may thus, in itself, delineate a vector which will point upwind to the source. This is especially true when complainant locations form a circle or crescent on a map, when odours are reported under relatively stable weather conditions. The projected centre of such circular point observations can be assumed to be the source area. Where an insufficient number of point observations are disclosed, the officer may make scheduled point observations in order to triangulate the source.

13.28 An estimate of wind velocity is useful in determining relative distances at which a source might be located from the complaint area. The tracking of an odour from a complaint area can be accomplished by making representative point observations along the odour route. To avoid odour fatigue officers may travel with their vehicle windows closed to maintain as relatively odour-free a vehicle as possible, then open them on arrival at a new point of observation for the purpose of comparison.

SUBJECT:

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

TOPIC: 14

THE ENVIRONMENTAL OFFICER'S
DUTIES AND RESPONSIBILITIES

OBJECTIVES:

The trainee will be able to:

1. List six items related to conduct and practices which must be given close attention in order to avoid any possibility of misunderstanding on the part of the public;
2. List the five parts of an inventory inspection or survey breakdown;
3. List the headings under which a complex survey report would be written;
4. List nine items of information which should be obtained when investigating a complaint;
5. Describe the three characteristics of a plume;
6. Name and sketch the various shapes of a plume;
7. Define: smoke, fumes, dust, mist, gas, vapour,

THE ENVIRONMENTAL OFFICER'S DUTIES AND RESPONSIBILITIES

14.1 The officer must be able to comprehend the law he enforces and relate it to the corresponding practical situation encountered in the field. Perhaps the most important single attribute that the officer should possess is the ability to make logical and reasonable judgments. Emotional stability is also an important quality. The officer must remain consistent and reliable without being readily influenced. He must be free of prejudices and biases which influence his judgment. He must be capable of analyzing situations for the objective facts and be able to enforce the law equally and firmly.

14.2 The ability of the officer to express himself completely and accurately, orally and in writing, is also important since his findings are always being reported for proper action. Oral expression ability is particularly important when an inspector testifies in court or explains a law or correct operating procedure to a plant operator, an owner or management.

14.3 Approach and appearance are also important, since the kind of appearance the officer makes before the public influences compliance directly by his ability to obtain respect for, and confidence in, his position and the Ministry. The officer's ability to perform his assigned duties effectively, given a technical proficiency, will stand or fall on the manner in which he conducts himself with the public. Since the officer is in the field most of the time, he is constantly dealing with people whose attitudes to him may be various, but whatever the attitude the officer must be polite and courteous, yet firm when required.

14.4 Ethics deal with principles of honesty, of right action. For the environmental officer ethical conduct and practices should be largely a matter of common sense, but there are several items which must be given close attention, particularly in a governmental agency, in order to avoid any possibility of misunderstanding on the part of the public:

1. Officers do not take any action or make any statement which interferes with any official act or decision of the Ministry;
2. Information acquired in any plant should never be disclosed to a competitor;
3. The law must be applied uniformly to all;
4. No firms or individuals can be recommended for air pollution control projects;
5. Reports must not in any way be falsified;
6. No gratuities should be accepted.

Making an Inspection

14.5 The classification of work and sources of air pollution break down so extensively that it is difficult to generalize on methods and principles, or to illustrate typical instances, but the steps taken in making an air pollution field inspection follow a pattern. An original inventory inspection is chosen here since it is usually the most thorough inspection conducted. The violation inspection, or other types of inspection differ according to the type of air pollution problems encountered.

The inspection breaks down into five parts:

1. Observation of plant exterior
2. Interviewing plant management
3. The physical inspection of equipment
4. Concluding the inspection
5. Presentation of the report

1. Observation of the Exterior

14.6 The outside of the plant is the first thing that the officer observes. The general layout, relative size and location of stacks, vents, and incinerators are particularly noted, by sketch or photograph. The officer estimates the possible contaminants that could be emitted into the atmosphere by such a plant. He tours the periphery of the plant, unless it is so small that it can be properly observed without the tour, and takes notes to make certain that all observations of visible air contaminant emissions are recorded. Particular attention is paid to points of observation, location of emission, time, colour, opacity of contaminant and accuracy of source description.

2. Interviewing Plant Management

14.7 The officer enters the plant, identifies himself and attempts to contact the top authority before conducting any business with any other person within the plant. The officer makes an effort to see the head of each plant personally, and in the event that this person is out, the next in authority and so on. This rule applies every time a plant is entered, unless the head of the plant designates a certain person to be contacted on future visits. This is a procedure which the dignity of the situation as well as common courtesy demands.

Before the plant is inspected, the officer informs management of his planned inspection of the premises. Usually permission to enter is granted without question, but at times it is necessary to explain that the Act gives the officer the right of entry. The officer either reads or shows the plant head the relative section of the Act. If permission is then refused, the officer does not enter forcibly but asks for a direct verbal refusal of entry and then informs the party concerned that by his refusal he is

not complying with the requirements of the Act. The officer then reports at once by telephone to headquarters for further instructions. Refusal of entry is rare, however, as most plants are prepared to co-operate. Where a routine inspection is planned, the possibility of refusal can be easily avoided by making an appointment in advance by telephone.

The officer then interviews the representative of plant management contacted. The interview serves to inform the management of the purpose of the inspection; imparts all information the plant manager may require regarding the air management programme; elicits any information the officer may require about the operation of the plant; and organizes the inspection.

The officer approaches any individual in the plant at his own level of speech and understanding. It is not done to use extremely colloquial English with an executive, but on the other hand, the officer should not assume a superior attitude and use complicated words with a person whose vocabulary is limited. The officer uses as clear expressions as will adequately describe whatever idea he is trying to implant. An interested and sincere, but not unfriendly attitude, creates the most desirable atmosphere for accomplishing the officer's purpose.

After the plant manager is informed of the visit, the officer then gathers preliminary data regarding the ownership of the plant, and the basic processes conducted by the plant. If the plant is exceptionally large or the processes employed are complex, the officer plans the inspection with the manager or whoever is subsequently detailed to accompany him. The company escort thus assists the officer in making a complete inspection.

In planning the inspection, the basic manufacturing processes are usually discussed. This provides an opportunity for the officer to ask questions about unfamiliar processes beforehand. This is often quite helpful, since the working area of the plant may be too noisy for normal conversation. The officer after learning of the steps taken in the process, can formulate a department-by-department inspection plan. He generally follows the flow of materials, the actual steps through which the manufacturing process is conducted. As this is discussed, the officer collects operating data which he can verify when he inspects the equipment. A friendly discussion of this nature at the beginning of the inspections saves much time.

3. The Physical Inspection

14.8 The plant to be inspected will comprise one of two distinct types of situations:

- (a) A plant consisting of individual pieces of equipment units, such as foundry, even though individual operations may be conveyorized.
- (b) Plants constructed on the basis of process units, i.e. equipment units interconnected by sealed or ducted flow systems.

In a plant that is relatively simple, it is only necessary to list equipment units. In a more complicated plant a generalized box-flow diagram may be required. Regardless of the type of plant, the officer should always provide the information or diagrams necessary to describe the plant to one who has not seen it.

The officer then inspects each equipment unit individually and acquires information from his observations and enquiry. In collecting inventory data it is essential

to write down the data at the time it is given to avoid errors. The officer should:

- (i) Identify the equipment units by function, commercial name and plant location
- (ii) Analyse the physical operation of the equipment, from influent to effluent, determine degree of operation and use, and note capacity and general operation or efficiency
- (iii) Check and evaluate all pertinent maintenance and operational practices

Much of the data can be observed directly at first hand, especially if the equipment unit is in full operation. Other data can only be elicited by asking developmental questions. If the latter approach is required, it is often best for the officer to be genuinely interested in the process, and to be curious about its operation. In dealing with statements, the officer may repeat them to ensure their accuracy. This can always be done by stressing the fact that an accurate record of plant information protects management against the use of incorrect information.

It should be noted that the officer does not directly order or instruct the operator in proper operation and maintenance procedures. The officer prescribes results rather than methods of obtaining results. He can discuss effective control practices as he knows them, but he is always careful to explain that the methods employed are up to management.

4. Concluding the Inspection

14.9 In concluding the inspection, it does no harm for the officer to compliment the plant operator on a well operated and clean plant. However, the operator is not told that he

"does not violate" the Act or Regulations when what is meant is that he is not violating it at the particular moment under consideration.

At this point, the officer may desire to review the results of the inspection with the plant operator. If the plant manager needs approval application forms for proposed new equipment, the inspector explains the procedure for submitting the applications and may supply the necessary application forms. If interest has been shown in the overall air pollution problem the officer may leave appropriate information publications.

The officer then takes his leave without unnecessary delay. The plant operator or manager has taken time from his usual duties to be with the officer and his time represents money. The leave is taken on a friendly note.

5. Writing the Report

14.10 After the officer completes the inspection, he completes his report. Since reports are usually short, they should be written as soon as the officer reaches his vehicle. Occasionally, when inspections are highly technical or are involved, and data at headquarters are required, the inspector may complete his report at headquarters.

The inspector must be able to select essential and relevant details and to describe them accurately and coherently. This is important since the inspector may have gathered a great deal of information, of which only a portion relates to the air pollution problems which may be encountered. The inspector attempts, however, to be complete and accurate.

Handling Complaints

14.11 Upon arrival in the vicinity, the officer first observes the source to determine if a violation is involved. If a violation is observed, the officer investigates, writes and serves a notice, if warranted. Then he visits the complainant. However, if no violation is immediately apparent, the officer contacts the complainant first. This is most often the procedure followed.

The officer makes every effort possible to avoid obvious identification of the complainant. He is particularly careful not to park an official vehicle too close to the complainant's residence should the complainant and the source be near each other. The officer considers the identities of all complainants to be confidential and never, under any circumstances, discloses them to anyone who is not an employee of the Ministry.

The officer then attempts to contact the complainant. If he is not at home, he leaves his calling card, and tries to contact him again at some other time. If he is at home, the officer identifies himself by name and agency in a friendly manner.

The ability to listen carefully is one of the skills the officer develops to get the facts. The officer is friendly, but dispassionate. He generally employs "non-directive" interview technique in that he allows the complainant to get the matter off his chest so that the facts of the situation can be calmly discussed. The officer also appreciates the fact that a person who is angry may honestly be motivated by a serious or chronic air pollution condition. In permitting the complainant to speak his mind, it is well for the inspector not to interrupt. It is particularly effective, however, when facts appear, for the officer to repeat them aloud for verification, and then jot them down.

After the complainant has expressed himself, the officer proceeds on a line of questioning which will determine the cause of the complaint, and the nature and source of the air pollution problems cited in the complaint.

The cause of the complaint, it should be noted, may not always involve air pollution. Although most complaints are justified, some will concern problems over which the Ministry has little or no control and in which air pollution may play a minor roll. These concern backyard feuds, natural contaminants, or perhaps resentment towards a nearby company. Although the officer may have no legal powers in such cases, he thoroughly investigates and attempts to correct all air pollution problems. If such complaints are unsubstantiated, the officer establishes the cause of the complaint, and documents the fact that no violation has occurred by recording the operational data of the equipment at the alleged source.

In verifying the validity of the complaint, the officer attempts to recognize contradictory, exaggerated and biased statements. He may politely challenge terms used by the complainant to denote frequency or inclusiveness such as "generally", "sometimes", "never", "all of the time", "rarely", in order to distinguish first hand knowledge or experience from speculation and inference. Precise indications of frequency may be crucial in tracking a source.

14.12 In order to obtain the necessary data, the officer enquires to obtain the following:

1. Name and location of source complained of
2. Frequency of annoyance or occurrence of plume
3. Time of day it was first noticed
4. Duration of each occurrence
5. Names and addresses of persons affected, if any
6. Location and extent of property damage, if any

7. Description and frequency of any illness alleged to have resulted from the air contaminants
8. Description of odours, if any involved
9. Any other information the complainant may have that will relate the problem to a specific piece of equipment.

14.13 While interviewing complainants, the officer does not promise legal action nor does he commit himself or the Ministry to any course of action. He may, however, explain to the complainant the law involved and the evidence that may be required to instigate legal proceedings, if asked.

During the course of the interview, the officer examines the complainant's property for any deposits or effects of air contaminants such as paint or acid stains, dusts, odours, flyash, etc. The pattern of fall-out of contaminants may indicate the direction from which they came. If a malodour is detected at the complainant's property, the wind direction can be determined for purpose of tracing the odour to its source.

From the facts gathered so far, the officer may already have a notion of what it is he should inspect, especially if he has identified contaminants and has observed definite evidence of damage, or detected odours on the complainant's property. In other cases he may know the identity of the contaminant but not the source of origin, and will first have to locate a possible source to inspect. In still other cases the contaminant may be completely unknown. The tracking and identification of contaminants are discussed later.

Effluent Formation and Composition

14.14 An effluent of air contaminants is a colloidal system, i.e. - a suspension of particles in the air or other gaseous medium, or a gaseous mixture released as a plume from a specific source outlet. Contaminant plumes may be either visible or invisible to the naked eye.

Visible effluents are those which consist of any one or combination of the following contaminants:

1. A sufficient concentration of a coloured contaminant gas, such as nitrogen dioxide (brown to yellow), bromine (reddish-brown), iodine (purplish), and chlorine (greenish-yellow). With the exception of these gases, however, virtually all contaminant gases significant in air pollution are colourless.
2. Aerosols, seen by light-scattering, greater than 0.4 micron.

14.15 In the case of aerosols, the visual threshold is dependant upon the intensity and the direction of the light source with respect to the observer, and the position and concentration of the effluent. The maximum visibility reduction occurs when the light source is directly opposite the observer and behind the effluent. As the observer changes his angle of position, the visual effect of the light scattering diminishes until, at a change of 180° of position, the visual effect is nil.

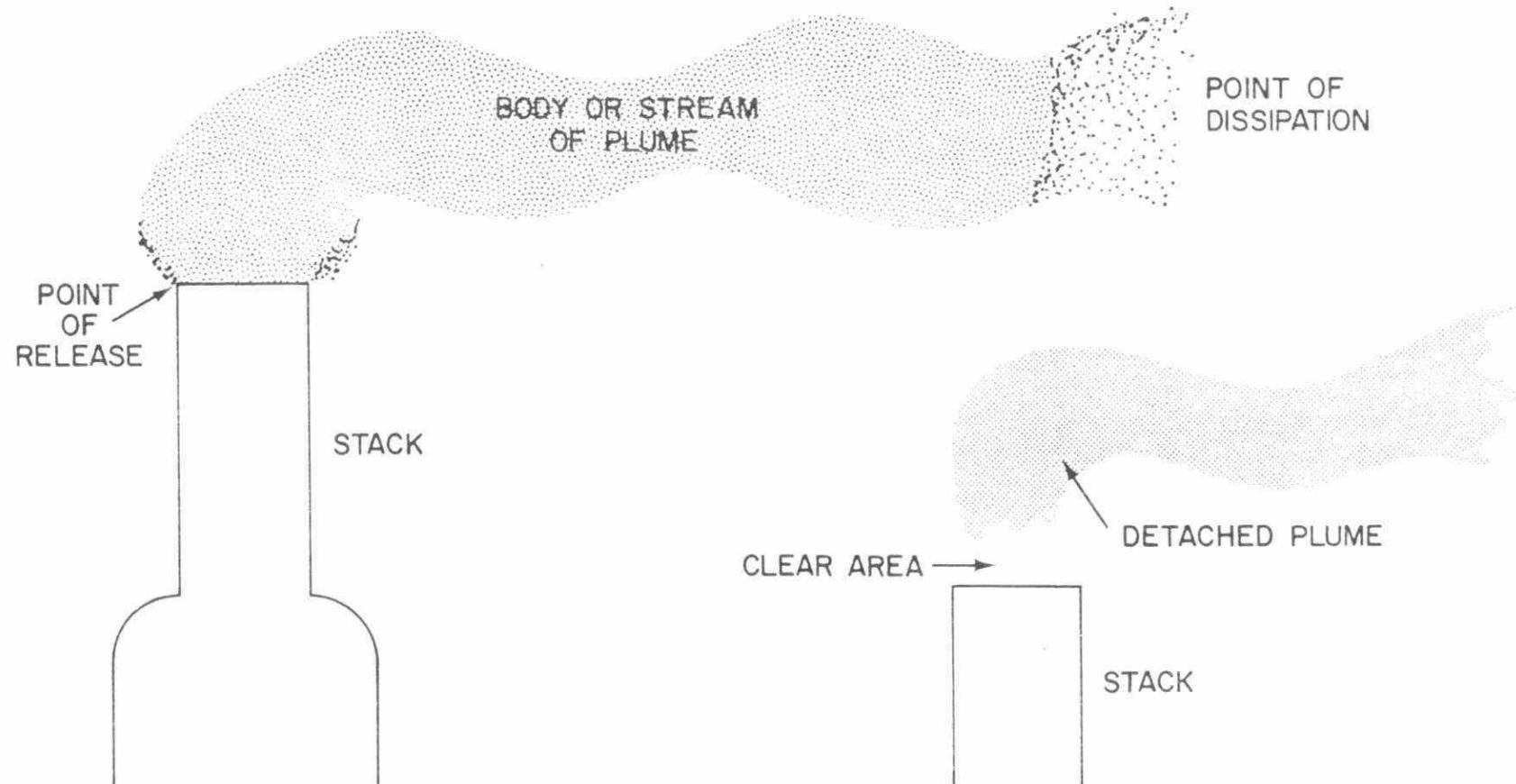
14.16 Effluents are invisible when the aerosols cannot be seen with the naked eye, or they consist of colourless gases, or the concentrations of visible materials are too low to be detected by the naked eye.

14.17 The plume or effluent is the flow itself of the contaminant-laden gas stream from a specific outlet such as a stack or vent. The plume (Figure 14-1), particularly when it is distinctly visible, is characterized by:

1. A point of release and formation just at the outlet of the stack or opening of a closed system, or a few feet above the outlet in the case of a "detached" plume
2. The body or stream, comprising most of the contaminants carried by the momentum of the escaping gases
3. The point at which the plume or effluent dissipates.

The breakdown of the plume structure is important. The point of discharge of the emission is the point at which the opacities of visible emissions are read or sampled. The stream or body of pollution provides some relative notion of quantity and velocity of the escaping contaminants, as well as other characteristics such as colour and particle size which help identify the plume. The point of dissipation is also important in determining whether or not the plume is a contaminant, water vapour or steam, or some combination of both. Depending on wind velocity, humidity and temperature, water vapour or steam tends to dissipate more rapidly than any contaminants contained in the effluent. The greater the humidity, generally speaking, the longer will be the steam plume.

14.18 General atmospheric conditions may also be indicated by the behaviour of the plume (Figure 14-2 and Table 14-1), and may be of significance in assessing the problem. A plume which rises straight up, for example, indicates rapid vertical mixing of contaminants



General structure of continuous and detached plumes, respectively.

Fig. 14-1, STRUCTURE OF A PLUME

PLUME BEHAVIOR AND RELATED WEATHER

Description of Visible Plume	Typical Occurrence	Temperature Profile-Stability	Associated Wind and Turbulence	Dispersion and Ground Contact
Irregular loops and waves with random sinuous movements; dissipates in patches and relatively rapidly with distance.	During daytime with clear or partly cloudy skies and intense solar heating; not favored by layer-type cloudiness, snow cover or strong winds.	1. Looping Adiabatic or super-adiabatic lapse rate-unstable.	Light winds with intense thermal turbulence.	Disperses rapidly with distance; large probability of high concentrations sporadically at ground relatively close to stack.
Roughly cone-shaped with horizontal axis; dissipates farther down-wind than looping plume.	During windy conditions, day or night; layer-type cloudiness favored in day; may also occur briefly in a gust during looping.	2. Coning Lapse rate between dry adiabatic and isothermal-neutral or stable.	Moderate to strong winds; turbulence largely mechanical rather than thermal.	Disperses less rapidly with distance than looping plume; large probability of ground contact some distance downwind; concentration less but persisting longer than that of looping.
Narrow horizontal fan; little or no vertical spreading; if stack is high, resembles a meandering river, widening but not thickening as it moves along; may be seen miles downwind; if effluent is warm, plume rises slowly, then drifts horizontally.	At night and in early morning, any season; usually associated with inversion layer(s); favored by light winds, clear skies and snow cover.	3. Fanning Inverted or isothermal lapse rate-very stable.	Light winds; very little turbulence.	Disperses slowly; concentration aloft high at relatively great distance downwind; small probability of ground contact, though increase in turbulence can result in ground contact; high ground level concentrations may occur if stack is short or if plume moves to more irregular terrain.

(Continued)

14-15

Description of Visible Plume	Typical Occurrence	Temperature Profile-Stability	Associated Wind and Turbulence	Dispersion and Ground Contact
Loops or cone with well defined bottom and poorly defined, diffuse top.	During change from lapse to inversion condition; usually near sunset on fair days; lasts about an hour but may persist through night.	4. Lofting Adiabatic lapse rate at stack top and above; inverted below stack--lower layer stable, upper layer neutral or unstable.	Moderate winds and considerable turbulence aloft; very light winds and little or no turbulence in layer below.	Probability of ground contact small unless inversion layer is shallow and stack is short; concentration high with contact but contact usually prevented by stability of inversion layer; considered best condition for dispersion since pollutants are dispersed in upper air with small probability of ground contact.
Fan or cone with well defined top and ragged or diffuse bottom.	During change from inversion to lapse condition; usually nocturnal inversion is being broken up through warming of ground and surface layers by morning sun; breakup commonly begins near ground and works upward, less rapidly in winter than in summer; may also occur with sea breeze in late morning or early afternoon.	5. Fumigation Adiabatic or super-adiabatic lapse rate at stack top and below; isothermal or inverted lapse rate above--lower layer, unstable or neutral, upper layer stable.	Winds light to moderate aloft, and light below; thermal turbulence in lower layer, little turbulence in upper layer.	Large probability of ground contact in relatively high concentration, especially after plume has stagnated aloft.

TABLE 14-1

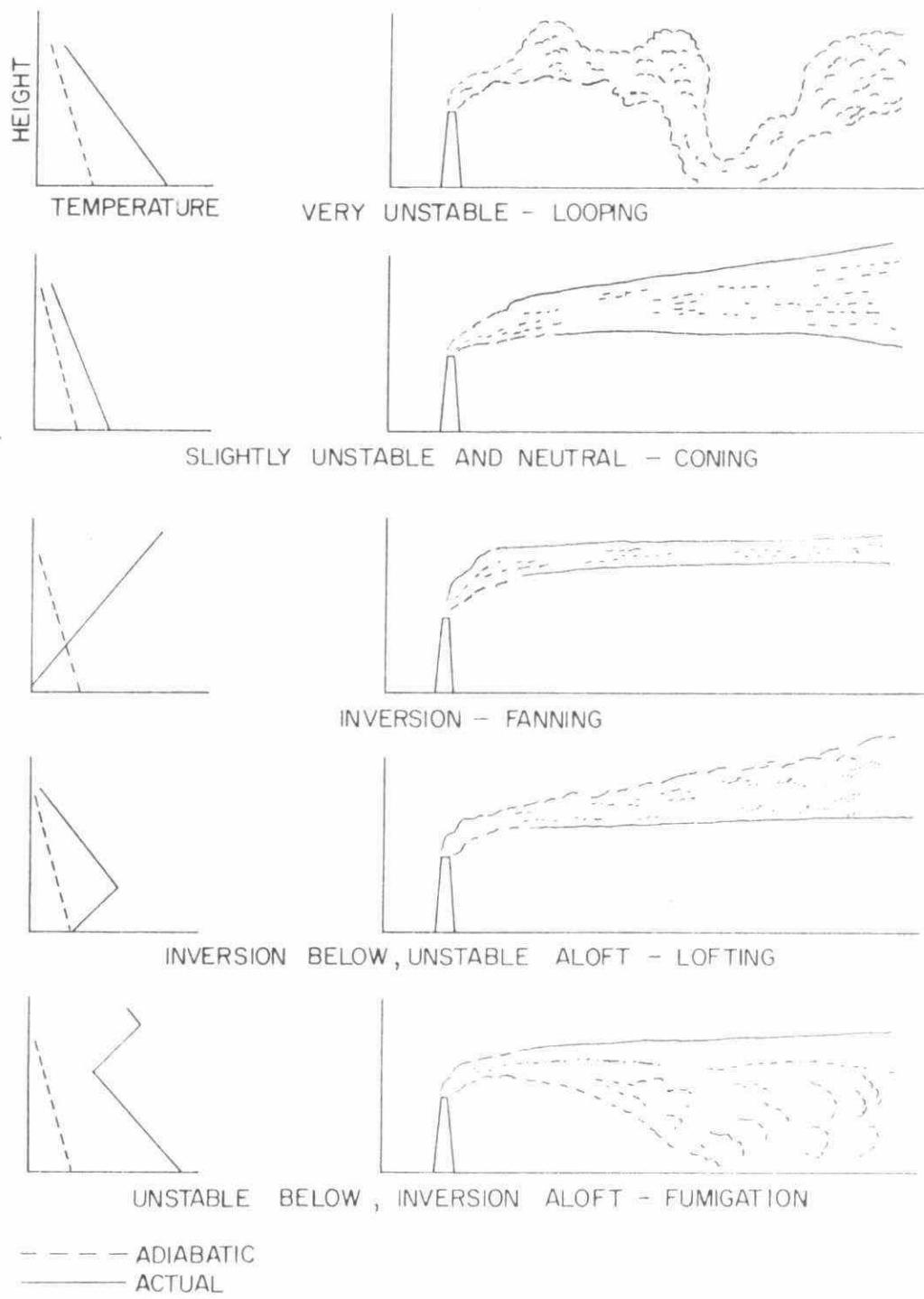


FIG. 14-2 EFFECT OF ATMOSPHERIC STABILITY ON PLUME BEHAVIOUR

favourable to the dissipation of the contaminants. Horizontal plumes, however, may cause fumigation of an area down-wind from the source of emission. The direction and extent of diffusion may then be indicated by the type of plume. A plume which disperses both vertically and laterally is known as a coning plume, in that the shape of dispersion is in the form of a cone. A coning plume generally results when wind speeds are in excess of 20 miles per hour. A looping plume occurs in turbulent or gusty atmospheres, and in general, results in good dispersion and only sporadic fumigation. A fanning plume generally results from a steady, and sometimes slow, wind stream, and tends to maximize the area of effective fumigation possible at relatively high contaminant concentrations.

14.19 In most cases, a trained observer can distinguish between smoke and fumes by colour, behaviour and dissipation point. Since a fume consists of relatively heavier molten liquid droplets which condense rather rapidly to a solid or mist, the point of dissipation is often closer to the stack outlet than in the case of smoke particles. Also, fume plumes often tend to form hazes sooner than do smoke plumes.

An experienced observer can also distinguish between emissions of smoke resulting from rubbish burning, fuel-oil burning, and even natural gas, when gas-fired boilers are severely out of adjustment, by colour and escape velocity of the body of the plume.

Of course, these generalizations must be supported by a thorough inspection of equipment and processes.

14.20 Since all substances become liquid, solids and gases at certain temperatures, any effluent or plume will consist of a variety of contaminants in various states of matter. Smoke, for instance, may consist chiefly of aerosols - carbon particles and solid or liquid particles (acids and aldehydes) of partially burned fuels - but may also consist of such gases as sulphur dioxide, oxides of nitrogen, or unburned vapours generated in the gaseous state.

Here again, the identity ascribed to the effluent is generally made in terms of its outstanding visual characteristic. For example, even though sulphur dioxide may be the most significant of the contaminants emitted from a stack, the effluent in which it is contained is frequently described as smoke due to the visible soot, carbon particles and fly-ash also contained in the plume.

14.21 The mere observation of a plume, however, does not result in its conclusive identification, the inspector will require knowledge of the specific conditions which cause the contaminant. The technical distinction between smoke and fumes cannot be made unless the process by which they are generated is described. With this in mind we may define each of the six categories of effluents: smoke, fumes, dusts, mists, gases, and vapours.

Smoke

14.22 Smoke is the visible effluent resulting from incomplete combustion and consisting mostly of soot, fly ash and other solid or liquid particles less than 1 micron in diameter. Depending upon the composition of the fuel or materials being

burned and the efficiency of combustion, various volatilized gases and organics such as aldehydes, various acids, sulphur dioxides, nitrogen oxides, and ammonia may also be emitted. When complete combustion occurs, only carbon dioxide, water vapour and small amounts of ash are emitted. Thus the generation of smoke depends on the efficiency of combustion equipment in relation to the fuel or material being burned.

Smoke will vary in colour, but will be generally observed as grey, blue, black, brown and white, sometimes yellow, depending upon the conditions under which certain types of fuels or materials are burned. The colour of smoke is generally a fairly good indication of the type of combustion problem encountered. Smoke which is grey or black in colour may indicate the material is being burned with insufficient air or inadequate mixing of fuel and air. White smoke usually results when the fire is cooled by excessive draughts of air, and may also be generated when the materials being burned contain excessive amounts of moisture. Brown or yellow smoke may result from the burning of semi-solid tarry substances such as asphalt or tar paper resulting from inadequate temperature and mixing. A blue or light blue colour is often associated with the burning of domestic refuse consisting mostly of paper or wood products. The blue plume contains little or no carbon or soot particles.

Fumes

14.23 Fume particles are generally less than 1 micron in diameter and will behave like smoke. Fumes more commonly consist of metals and metallic oxides and chlorides. Also contained in fumes are common solid particulates such as fly ash, carbon, mechanically produced dust and gases such as sulphur dioxide. The fumes principally emitted, however, are actually dusts condensed from the more volatile elements in the melting of metal such as zinc, sulphur, lead, and others. The officer, therefore, will probably be more concerned with metallurgical fumes, and frequently with emissions from galvanizing operations.

Dusts

14.24 Dusts are minute particles released in the air by natural forces or by mechanical processes such as crushing, grinding, melting, drilling, demolishing, shovelling, sweeping, sanding, etc. Dust particles are larger and less concentrated than those in colloidal systems such as smoke and fumes and will settle fairly quickly on surfaces. A dust effluent, however, may also contain many submicroscopic particles.

Dusts are produced from virtually every human activity as well as from the natural environment. Some dusty industries include mineral earth processes such as ceramic and cement manufacturing, calcining, and woodworking and feed and flour industries. Dust particles generally exceed 1 micron in diameter and are readily controlled by centrifugal separators, cloth filters and electrostatic precipitators.

Mists

14.25 Mists are liquid particulates or droplets, about the size of raindrops, such as fog, and are formed by condensation of a vapour, or atomization of a liquid by mechanical spraying. Mist droplets contain contaminant material in solution or suspension. The impregnation and coating of building materials with asphalt, or the manufacture or heating of asphalt at batch plants may produce hazes or fogs containing droplets of liquid asphalt. Paint spraying operations emit liquid particulates containing organic solvents, pigments and other materials. Mists may also be emitted from control devices such as cyclones and scrubbers, using a liquid air cleaning medium. Acid particulates, such as chromic and sulphuric acids produced from chrome plating operations, may also form mists when exhausted to the atmosphere.

It is important to distinguish between a cloud of liquid aerosols and a mist of liquid droplets especially in relation to liquid contaminants involving sulphur compounds. For example, sulphur trioxide exists at normal temperatures as a liquid, but when exposed to stack temperatures encountered in large oil-burning installations, sulphur trioxide becomes a gas, and, after contact with sufficient moisture in the air, forms as a white-to-blue plume several feet above the stack (detached plume). After further contact with moisture in the air, the sulphur trioxide is transformed to a weak sulphuric acid mist. When the moisture in the mist evaporates, a sulphuric acid aerosol is formed, and if the concentration is

sufficient, a visible cloud. The acid mist is more dangerous to health than the aerosol cloud, since the latter can be inhaled and exhaled without effect, whereas the former adheres to respiratory tissue.

Gases

14.26 A gas is a state of aggregated matter or a fluid of freely-moving molecules tending to expand indefinitely and to diffuse and mix readily with other gases. As pollutants, gases include a large variety of inorganic and organic gases which may have noxious, malodorous, toxic, or corrosive effects, or which may have an effective smog-producing potential.

Vapours

14.27 A vapour is the gaseous phase of a substance which at normal temperature and pressure is a liquid or solid. The most important vapour in the air pollution problem is that which results from the evaporation of petroleum products, such as the unburned gasoline vapours in automobile exhaust. Gasoline vapours also originate from processes in which volatile products are maintained in storage tanks and from the operation of pumps, compressors and blowers required for moving liquid gas streams.

Another principal source of vapours originates from the consumption, marketing and manufacture of paints and other coating products containing organic solvents which are used to dilute or extend surface coatings. These are released to the atmosphere upon application.

Atmospheric Humidity and Water Vapour Plumes

14.28 A plume containing large amounts of water vapour will be visible for longer distances under conditions of high atmospheric humidity. The moisture content of the air is great enough so that water droplets in the plume are prevented from evaporating. Thus the water remains in the visible liquid phase instead of changing into the invisible vapour phase.

14.29 A "detached plume" (Figure 14-1) occurs when a moisture-laden effluent is emitted from a stack at a temperature above the boiling point of water. The plume becomes visible only after the effluent has been cooled down by the air to a temperature where the water vapour condenses to the liquid droplet state. If the atmosphere is hot, the cooling will take some time. Then, there will be a space between the top of the stack and the point where the plume becomes visible.

14.30 Water plumes can be distinguished from plumes of white particles in several ways:

- (a) A pure-water plume disappears rather quickly and has an appearance of wispiness as it evaporates
- (b) The greater frequency of occurrence and a greater length of plume in cold, wet weather than in warm, dry weather
- (c) The detachment of the visible plume from the top of the stack in hot, dry weather, when it takes the plume longer to cool to its saturation point

- (d) If there is other material mixed with the water, the plume of this material will remain after the water has evaporated.

Effects on Reading of Plume Density

14.31 The stronger the wind, the more it dilutes the plume and the less dense the effluent appears.

14.32 If the wind is blowing a plume toward an observer, he is looking through the length of the plume. He will be looking through a longer portion of the plume than if he were looking through the width of the plume. Thus, the plume will appear more dense.

14.33 An increase in the illumination of a plume results in an increase in the contrast between the plume and its background causing the plume to look more dense. Cloudy skies cut down on the illumination and thus the contrast.

14.34 An observer picks out a contrasting background against which to view a plume. White smoke read against a white cloud background or black smoke read against a dark cloud background reduces the contrast and makes the plume appear less dense.

14.35 A plume disperses more rapidly in an unstable atmosphere than in a stable atmosphere. Downwind, a coning plume looks less dense than a fanning plume. However, if an observer looks at them both while they are near the stack, their densities will be equal since they have not begun to spread out.

14.36 When an observer looks at a plume through a hazy atmosphere the contrast between the plume and its background is weakened. The plume, under these conditions, does not look as dense as it would on a clear day.

14.37 When an observer looks at a white plume with the sun in front of him, the plume scatters more light toward the observer than is the case for an observer looking at the plume with the sun at his back. This increased scattering by the white plume itself results in a higher density reading by the observer looking toward the sun. For dark plumes on a clear day, the viewer looking toward the sun also sees a plume that appears to be more dense. On an overcast day, the two viewers agree on the density of the plume.

SUBJECT:

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

TOPIC: 15

CLAY PRODUCTS

OBJECTIVES:

The trainee will be able to:

1. List and briefly explain the four stages of firing clay products:
 1. Dehydration
 2. Oxidation
 3. Vitrification
 4. Fusion;
2. Briefly describe the operation of kilns of the following types:
 1. Intermittent up-draught
 2. Intermittent down-draught
 3. Continuous tunnel;
3. List the air contaminant emissions from the various brick manufacturing operations.

CLAY PRODUCTS

15.1 Ceramics in general are made primarily from clay, a decomposition product of the mineral feldspar which is the principal constituent of granite and gneiss - both igneous rock.

15.2 Pure clay has the formula $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$. It is found mixed with quartz grains (SiO_2) and undecomposed feldspar and in use contains feldspar, lime magnesia, iron compounds and silica. The first three are fluxes causing the "body" to melt and run together; iron imparts various colours, and silica has hard refractory properties.

15.3 In brickmaking, dyes may be added to the natural clay to obtain different colours. Manganese oxide is added to obtain various degrees of brown; the more added the deeper the shade of brown. Limestone is added to make yellow bricks; the more added the more yellow the brick.

15.4 The raw materials of ceramics are prepared by weathering, calcining of flints, and crushing; are mixed in required proportions; shaped by either "throwing", handmoulding, jelling (one side formed on a plaster of paris mould and the other by a profile tool), extrusion, pressing, turning (in the dry state), or slip casting, when the slip (alkaline solution of clay) is poured into plaster moulds; and is then dried in either intermittent or continuous driers.

15.5 Firing of clay products can be discussed under four headings: Dehydration, Oxidation, Vitrification, and Fusion.

15.6 Dehydration. Dehydration, or "water-smoking," involves the elimination of water. Free water, or moisture, is driven off in the temperature zone 21° to 150° C. Water combined chemically in the

hydrous minerals is evolved between 150°C and 590°C .

15.7 Oxidation. Oxidation normally is completed in the temperature zone 345° to 955°C . Organic materials are burned, and carbonates, sulphides, and sulphates are decomposed. The principal gases evolved are carbon dioxide, sulphur dioxide, and sulphur trioxide. It is important that the rate of heating during this period be carefully controlled to insure complete oxidation of carbon before partial fusion of the clay surface prevents the escape of carbon dioxide. Bloating caused by bubbles of trapped gas, and "black-coring" caused by unoxidized carbon, may be the result of too fast a heating schedule.

15.8 Vitrification. Vitrification is the condition of partial fusion, whereby a glassy bond is formed around predominantly unfused particles, resulting in increased hardness and decreased porosity and volume. Vitrification of common clays and shales may begin as low as 900°C and continue to the softening point. The softening point is the stage at which sufficient fusion has occurred to cause deformation.

The degree of vitrification of a clay body is indicated by its porosity, volume shrinkage, hardness, and depth of colour.

15.9 Fusion. Fusion is defined as the change of state of a substance from the solid to a liquid phase. In most ceramic materials fusion takes place over a considerable range of temperature. The range of partial fusion before deformation is known as the vitrification range. In the firing of heavy clay products fusion is considered to be the point where deformation occurs. In addition to warpage of the ware, fusion is indicated in red-burning clays by increased shrinkage, density, and depth of fired colour; a dark red or mahogany

brown colour with a smooth, or sometimes blistered, hard glassy surface is typical. Fusion of limy clay occurs rather suddenly and is marked by warpage, increased density and shrinkage, and often by a greenish cast on the yellow fired colour.

Ceramic Kilns

15.10 These are generally classified as:

1. Intermittent - (a) Up-draught
 (b) Down-draught
2. Continuous - (a) Ring type
 (b) Tunnel

Normally "open flame" kilns are used in which the goods are directly heated by the flames and hot gases. Where such contact would spoil the products, ceramics are packed in refractory receptacles, called "saggers", or muffle-type kilns are used.

Intermittent or Periodic Kilns

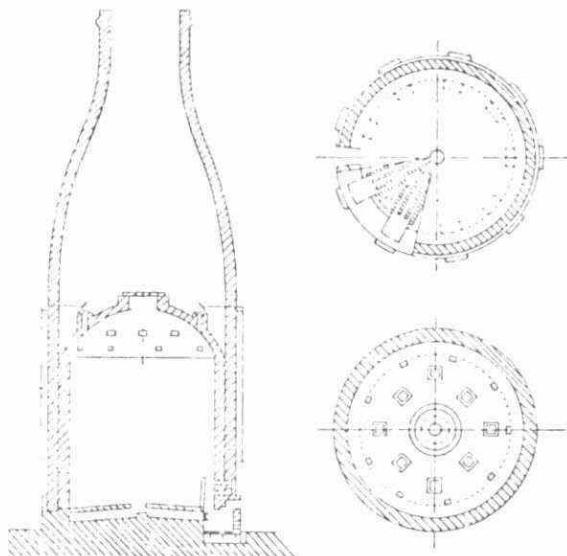
15.11 These are still largely employed where a limited amount of one product is required. Fuel consumption is high because the kilns have to be cooled after each batch, to be laboriously emptied and refilled. The method does not lend itself to mass production techniques; does not ensure very uniform time/temperature exposure of wares; and usually involves heavy breakages.

Where coal fires are used for heating, smoke is particularly liable to be produced during the second stage due to cooling of volatiles by the wares and the kiln walls.

Intermittent Up-draught Pottery Kiln

15.12 Usually circular in plan, with fire-places arranged at regular intervals around the base. A "bottle" kiln is illustrated in Figure 15-1. The flames take two separate routes:

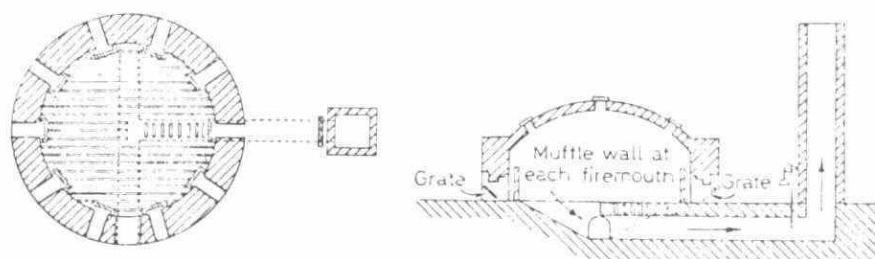
1. directly up through flues in the walls into the oven and out through the dome to the chimney; and



Up-draught pottery kiln

(From *The Efficient Use of Fuel*, by permission, of the Controller, H.M. Stationery Office)

FIGURE 15-1



Down-draught kiln for firing heavy clay ware

(From *The Efficient Use of Fuel*, by permission of the Controller, H.M. Stationery Office)

FIGURE 15-2

2. through the flues beneath the sole covering into the oven.

Old practice is to "bait" (stoke) at intervals of 3 hours. Wide variations in temperature and excess air result.

They have been largely superseded by continuous car tunnel kilns fired by natural gas, electricity or fuel oil, or by modern intermittent kilns fired by natural gas or electricity.

Intermittent Down-draught Kiln

15.13 The are used for heavy clay ware, refractory goods, etc., and may be one single chamber or two storey (continental), the upper chamber of which is used to fire clay ware at a lower temperature by means of flue gases from the lower chamber.

The kilns are circular or rectangular in plan with a number of fire-places arranged around the base. The hot gases rise to the dome and descend through exit holes in the sole to the flue. Flue losses are lower than with up-draught kilns. An example of the round or "beehive" kiln is illustrated in Figure 15-2.

Fuel for Intermittent Kilns

15.14 For the first stage short-flame coal or coke may be used and combustion completed in the fire-mouth with excess of air. This fuel is mixed with long-flame coal for the second stage. Long-flame coal is essential for the third stage to carry the heat to all parts of the kiln. Fuel with low ash and sulphur content is preferred. A deep fuel bed

providing CO₂ is advantageous during the later stages, the fire being built up gradually during the second stage, usually by feeding alternate fires so that hot secondary air from the intermediate fires burns the volatiles from those freshly charged. Close control of firing and air supply is essential to avoid temperature fluctuations and ensure sufficient oxidation with fuel economy. CO₂ should be 9% to 12%. In the final period firing should be "little and often". The glowing fuel is pushed down into the firemouth and the fresh charge of coal placed at the front and on top of the fuel bed. The "coking" method may sometimes be used, the fresh charge being sometimes placed on a sloping refractory table above the main fire.

These kilns are readily convertible to natural gas, and many have been so converted in order to comply with air pollution control regulations.

15.15 Minimizing Smoke from Down-Draught Kilns

1. Reducing water smoking period by pre-drying ware (usually accomplished on cars in a tunnel dryer);
2. Charging alternate fires with small quantities, putting fresh coal at the front, or using mechanical stokers;
3. Admitting secondary air at 500°C above fuel bed, controlled to give between 8 - 12% CO₂ in the flue gases;
4. Removing ash and clinker from one fire at a time; and
5. Keeping structure in good repair.

Where a reducing atmosphere is essential to convert ferric to blue ferrous oxide, tertiary air is introduced in the flues to consume smoke.

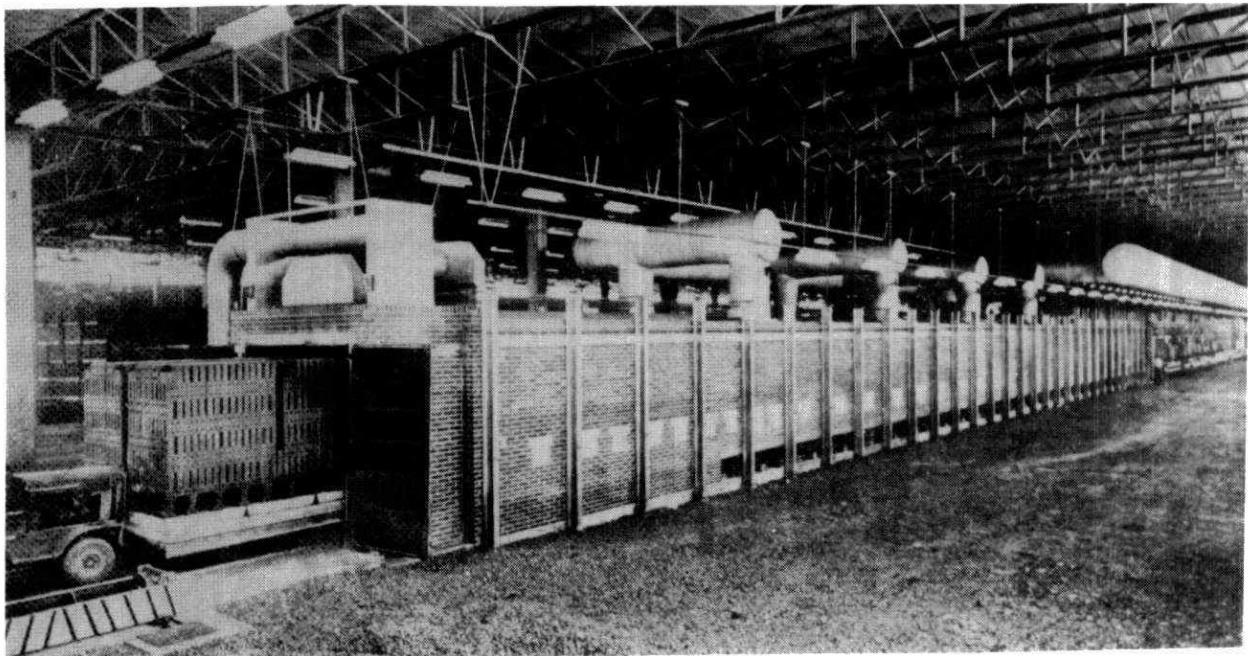
Continuous Kilns

15.16 The economic advantages of mass production and high thermal efficiency are obtained from the use of continuous kilns. Because of the low fuel consumption and the refinement in control offered, natural gas, fuel oil, or electricity may be used, according to the quality and class of product made.

With all continuous kilns heat from cooling goods is used to pre-heat secondary air required for combustion, and primary air may also be pre-heated in this way. Some of the heat recovered may be transferred to different parts of the kiln when hot air circulation systems are used, or hot air may be transferred for extraneous use in driers. The hot kiln gases are used to pre-heat the incoming ware, so that the main heat losses are confined to those due to radiation, convection and conduction from the outside walls.

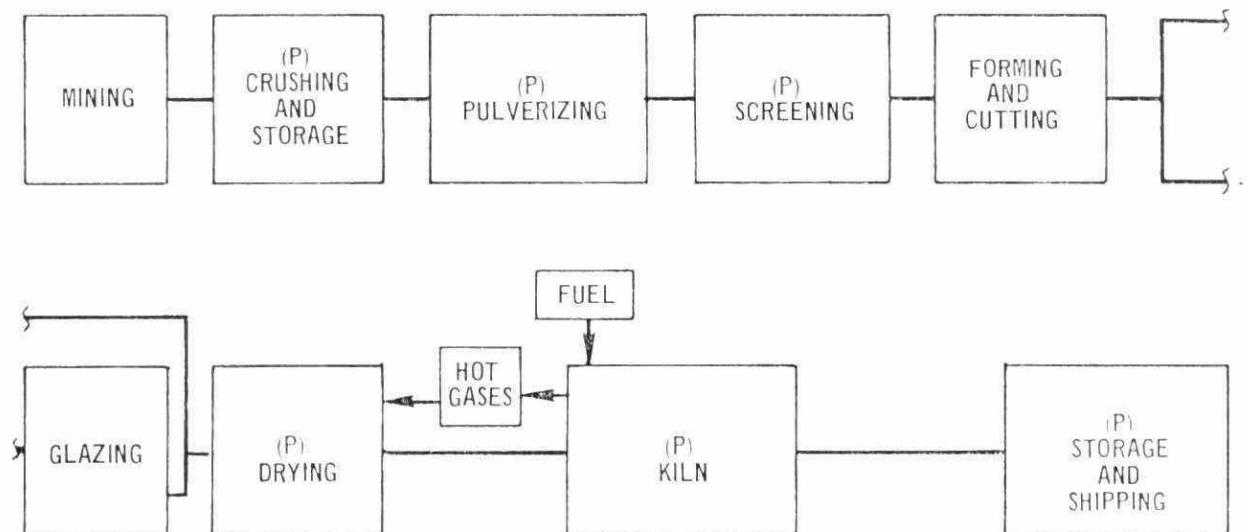
Hoffman Kiln

15.17 The Hoffman Kiln comprises an annular (ring like) chamber divided by brick partitions, with small openings at the bottoms, into 12 or more compartments, each connected by flue to a central chimney. The flue of number 12 compartment leading to the chimney is open, drawing air through all the loaded compartments. While #1 chamber is being loaded, 2 is being emptied, the bricks in 3, 4, 5 & 6 compartments are cooling, 7 & 8 are burning at maximum temperature and 9, 10, 11 & 12 are drying. The opening between 12 and 1 is covered to prevent draught passing. When 1 is full, the charging door is bricked up and the cycle moved around one compartment.



Firing brick in a modern continuous-tunnel kiln
 (Photo courtesy Canadian Structural Clay Association, Willowdale)

FIGURE 15-3



Basic flow diagram of brick manufacturing process. "P" denotes a major source of particulate emissions.

FIGURE 15-4

Continuous Tunnel Kilns (Figure 15-3)

15.18 In car tunnel kilns the pre-heating, firing and cooling zones are fixed, the goods travelling through these zones on cars or carriages operated by an external pusher mechanism. These tunnels may be either straight or annular, some 100 - 300 ft. in length, a moving hearth being used in the annular kiln instead of cars. The straight tunnel has the advantage of acting as a conveyor between factory departments, and economy of labour may be combined with efficient use of fuel. Such plants assist in maintaining a flow of material on modern mass production lines.

The wares move on either a truck covered with refractory material, a moving refractory sole, or a conveyor of heat resisting metal. The firing zone is in the centre.

The "counterflow" system is generally used, by which air and gases travel in the opposite direction to the ware, air cooling the fired ware and becoming pre-heated, and gases of combustion pre-heating the ware as it approaches the firing zone. Heat recovery and the avoidance of cooling losses halves the fuel consumption per ton of ware as compared with intermittent kilns.

Types of Tunnel Kilns

15.19

1. Open Flame

(a) Firebox type.

May be coal-fired with fireboxes 8 - 12 ft. apart - used when a high uniformity of heat distribution is not essential.

(b) Top-fired type.

Fired as Hoffman Kiln - used for brickmaking.

(c) Multi-burner type.

Uses gas or oil burners close together - distribution of hot gases can be controlled to give a more uniform firing temperature.

2. Muffle and Semi-muffle

Used for delicate ware which might be affected by contact with flame or products of combustion - sometimes preferred to use of saggers.

Radiant burners for gas and oil-firing which give a short intense flame which does not impinge on the ware may be used instead of muffles.

3. Electric Furnaces

Electric tunnel kilns are used increasingly for firing on-glazed decorated pottery, for which only 700° to 800°C is required, and where colours are sensitive to fumes. They are used for "glost" firing (i.e. firing glazes on ware previously fired at a higher temperature) for the same reasons.

Firing and Salt Glazing Stoneware

15.20 Common salt or borax (sodium borate) is thrown into the kiln when firing is approaching its final stage. Sodium chloride volatilizes at 800°C and forms a glaze in contact with clay at about 1,150°C. It dissociates, the chlorine combining with water vapour and escaping as hydrochloric acid, the sodium combining with the silica and to a lesser extent with alumina, to form a thin glaze of sodium aluminum silicate.

Where borax is used, with or instead of sodium chloride, sodium-silica-borate glaze is formed. Firing is usually in down-draught intermittent kilns, the cycle being about 3 weeks. The salt is either thrown through fire holes on to the glowing fuel at the back of each firebox, or through openings in the top of the kiln. Salting is done in several operations at half-hourly intervals, the temperature of the kiln being restored after each drop due to volatilization. 2 pounds of salt cover about 1 ton of ware.

Glazed Brick

15.21 A boron glaze frit (ceramic composition) is sprayed on the exposed surface of unfired bricks prior to firing. Suitable metal oxides added to the frit provide a wide range of glaze colours.

Air Contaminant Emissions and Controls

15.22 Particulate matter is the primary emission in the manufacture of bricks. The main source of dust is the materials handling procedure, which includes drying, grinding, screening, and storing the raw material, as shown in the basic flow diagram, Figure 15-4. Combustion products are emitted from the fuel consumed in the curing, drying and firing portion of the process. Fluorides, largely in gaseous form, are also emitted from brick manufacturing operations. Sulphur dioxide may be emitted from the bricks when temperatures reach 2500°F (1370°C) or greater; however, no data on such emissions are available.

15.23 A variety of control systems may be used to reduce both particulate and gaseous emissions. Almost any type of particulate control system will reduce

emissions from the material handling process, but good plant design and hooding are also required to keep emissions to a minimum.

15.24 The emissions of fluorides can be reduced by operating the kiln at temperatures below 2000°F (1090°C) and by choosing clays with low fluoride content. Satisfactory control can be achieved by scrubbing kiln gases with water; wet cyclonic scrubbers are available that can remove fluorides with an efficiency of 95 per cent, or higher.

15.25 Emission factors for brick manufacturing are presented in Table 15-1. Insufficient data are available to present particle size information.

EMISSION FACTORS FOR BRICK MANUFACTURING WITHOUT CONTROLS^a
EMISSION FACTOR RATING: C

Type of process	Particulates		Sulfur oxides (SO _X)		Carbon monoxide (CO)		Hydrocarbons (HC)		Nitrogen oxides (NO _X)		Fluorides ^b (HF)	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Raw material handling ^c												
Dryers, grinders, etc.	96	48	—	—	—	—	—	—	—	—	—	—
Storage	34	17	—	—	—	—	—	—	—	—	—	—
Curing and firing ^d												
Tunnel kilns												
Gas-fired	0.04	0.02	Neg ^e	Neg	0.04	0.02	0.02	0.01	0.15	0.08	1.0	0.5
Oil-fired	0.6	0.3	4.0S ^f	2.0S	Neg	Neg	0.1	0.05	1.1	0.55	1.0	0.5
Coal-fired	1.0A	0.5A ^g	7.2S	3.6S	1.9	0.95	0.6	0.3	0.9	0.45	1.0	0.5
Periodic kilns												
Gas-fired	0.11	0.05	Neg	Neg	0.11	0.05	0.04	0.02	0.42	0.21	1.0	0.5
Oil-fired	0.9	0.45	5.9S	2.95S	Neg	Neg	0.1	0.05	1.7	0.85	1.0	0.5
Coal-fired	1.6A	0.8A	12.0S	6.0S	3.2	1.6	0.9	0.45	1.4	0.70	1.0	0.5

^aOne brick weighs about 6.5 pounds (2.95 kg). Emission factors expressed as units per unit weight of brick produced.

^bBased on data from References 3 and 6 through 10.

^cBased on data from sections on ceramic clays and cement manufacturing in this publication. Because of process variation, some steps may be omitted. Storage losses apply only to that quantity of material stored.

^dBased on data from References 1 and 5 and emission factors for fuel combustion.

^eNegligible.

^fS is the percent sulfur in the fuel.

^gA is the percent ash in the coal.

TABLE 15-1

SUBJECT:

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

TOPIC: 16

IRON AND STEEL PRODUCTION

OBJECTIVES:

The trainee will be able to:

1. Briefly describe the construction and operation of a blast furnace for smelting iron ore;
2. Sketch a basic flow diagram of the iron and steel making processes, indicating the major sources of particulate emissions;
3. Briefly describe the operation of the following, including emissions to be expected:
 1. Bessemer converter process
 2. Basic oxygen furnace
 3. Open-hearth furnace
 4. Sintering plant
 5. Coke oven plant
 6. Cupola furnace
 7. Electric-arc furnace
 8. Core ovens.

IRON AND STEEL PRODUCTION

Iron Ore

16.1 Iron ore is the term applied to a natural iron-bearing mineral in which the content of iron is sufficient to be commercially usable. The most common iron minerals are hematite (Fe_2O_3), magnetite (Fe_3O_4), siderite ($FeCO_3$), and pyrite (FeS). Limonite may be considered as magnetite plus water. Taconite and jasper are names referring to a wide variety of iron-bearing rocks.

Beneficiation

16.2 Most iron ore destined to be used in the large steel-making plants is "beneficiated" near the mine site. "Beneficiation" is a generic term applied to the various kinds of treatment that may be given to iron ore to make a better raw material charge for iron-making blast furnaces. Such treatment ranges from simple washing to highly complex methods of concentrating the ore for which the ore may be crushed, magnetically separated, formed into pellets, and baked. Transportation savings are great. In the case of magnetic taconite about two tons of mineral are removed for each ton of pellets shipped.

Direct Reduction

16.3 Various processes are now used which concentrate ores to a very high content of iron. Some of these "direct-reduced" ores are made into pellets, others into briquettes.

In one process magnetic taconite pellets are fed by hopper into "metallizing" furnaces. A gas mixture of hydrogen, carbon dioxide, carbon monoxide, water vapour and nitrogen is forced into the bottom of the furnaces and rises through the pellets, picking up oxygen from them. The gases are recovered at the top of the furnaces and are usually re-formed in a closed system for re-use, or alternatively the gases may be burned as a fuel. The pellets resulting from this process

may contain 95 per cent iron.

In another method the iron ore is ground to fine particle size, heated, and reduced with hydrogen to remove practically all the contained oxygen. The high content iron fines are then pressed into dense briquettes with iron content ranging from 86 to 92 per cent.

Direct-reduced iron ore is beginning to make changes in the iron and steel industry, as some is now being charged directly into electric or basic oxygen furnaces, and so bypassing the traditional blast furnace.

Smelting

16.4 Iron ore is smelted in the blast-furnace (Figure 16-1), so-named because of the continuous blast of air required to bring about the necessary heat and chemical reactions in the raw materials. As much as four and a half tons of air may be needed to make one ton of pig iron. It consists of a large cylindrical furnace casing lined with refractory firebricks. It may be up to 100 feet high and capable of producing 500 tons or more a day.

The blast-furnace operates continuously and is generally run for a period of years, or until the lining burns out. The duration of furnace operations from start to finish is known as a "campaign". The solid raw materials are fed in from the top, and consist of iron ore, metallurgical coke and limestone, the latter used as flux. This washes out many of the impurities in the ore, producing a slag which separates from, and floats on the top of, molten iron.

Super-heated air, ranging from 760° to $1,150^{\circ}\text{C}$, is blown in at points near the bottom of the furnace through a set of tuyeres. This acts on the fuel of the charge and generates intense heat (over $1,650^{\circ}\text{C}$), the gases given off pass through the charge and reduce the iron oxide to the metallic state. The gases are predominantly nitrogen and carbon monoxide. In this reducing atmosphere no sulphur is oxidized so that the furnace top gases are free from sulphur dioxide. The carbon monoxide acts as a reducing agent on the

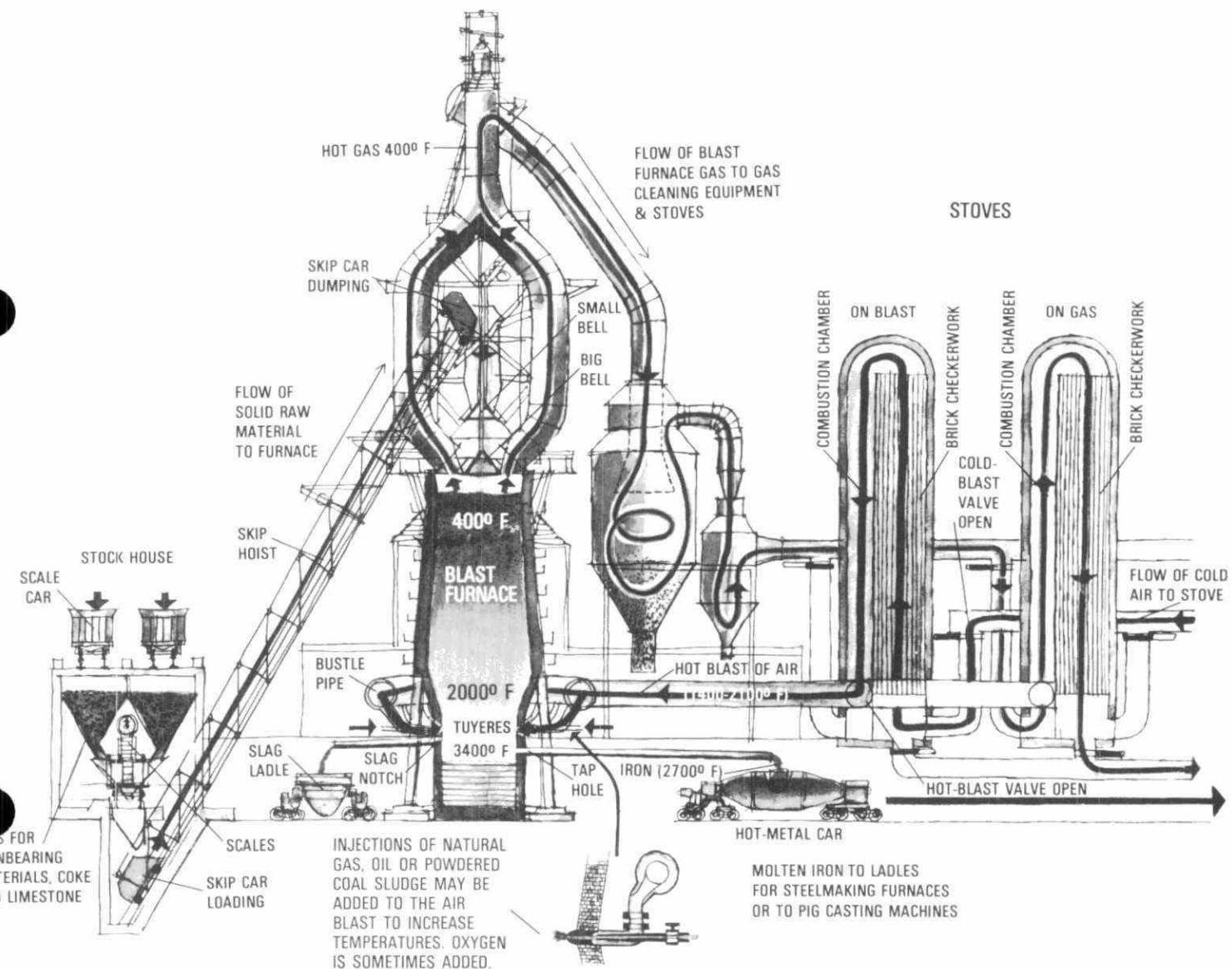


FIG. 16-1 - THE BLAST FURNACE
(Courtesy of Steel Company of Canada Limited)

The flow of solids, air and gases diagrammed here reveals the sophistication of today's blast furnaces. Ore, coke and limestone work their way down the "stack" which is a huge steel shell lined with heat resistant brick. The combination of increasing heat and resulting chemical changes gradually causes the release of iron from its ore in molten form. The heavy metal collects at the bottom (hearth), and the lighter molten impurities float on the iron. Removal of metal and slag is frequent.

iron oxide and the ore is reduced to metallic iron. The reduced iron melts and falls to the bottom of the furnace, on its way absorbing carbon and silicon. The slag floating on the surface of the iron at the bottom of the furnace is tapped now and again, before the metal itself is tapped at a lower level. It takes a charge about 8 hours to pass through a furnace.

The top of the furnace casing is sealed by means of two conical "bells" which fit into the lower part of the charging hopper; an arrangement that permits charging but precludes the escape of the gases. These waste gases (blast-furnace gas) pass into a "down-comer" and are used, after cleaning, to heat the air blast for the furnace itself. Average analysis of this gas is:

27.5% CO 11% CO₂ 61.5% N₂ etc.

Originally, when the molten iron was tapped it was allowed to run along a sand channel from which small lateral channels branched off. The main channel was known as a "sow" and the others as "pigs"; hence the term "pig iron".

In a modern steelworks the molten iron is run off into transfer rail cars, which deliver the molten metal either to a "mixer" facility (a holding vessel used to improve the uniformity of the iron and as a reservoir), or directly to ladles for charging the steelmaking furnaces. Most iron made in blast furnaces is used in steelmaking, but some of the molten iron goes to a casting machine where it is solidified in moulds as "pigs" for the cast iron foundry industry. Pig iron consists of about 93 per cent iron and 7 per cent extraneous elements.

STEEL MANUFACTURING PROCESSES (Figure 16-2)

16.5 Steel, generically, is a crystalline alloy, mainly of iron and carbon, which attains greater hardness when quenched from above its critical temperature than when cooled slowly. Carbon is the most important constituent because of its effect on the strength of the steel and its ability to harden. Other constituents that may be present as impurities or as added

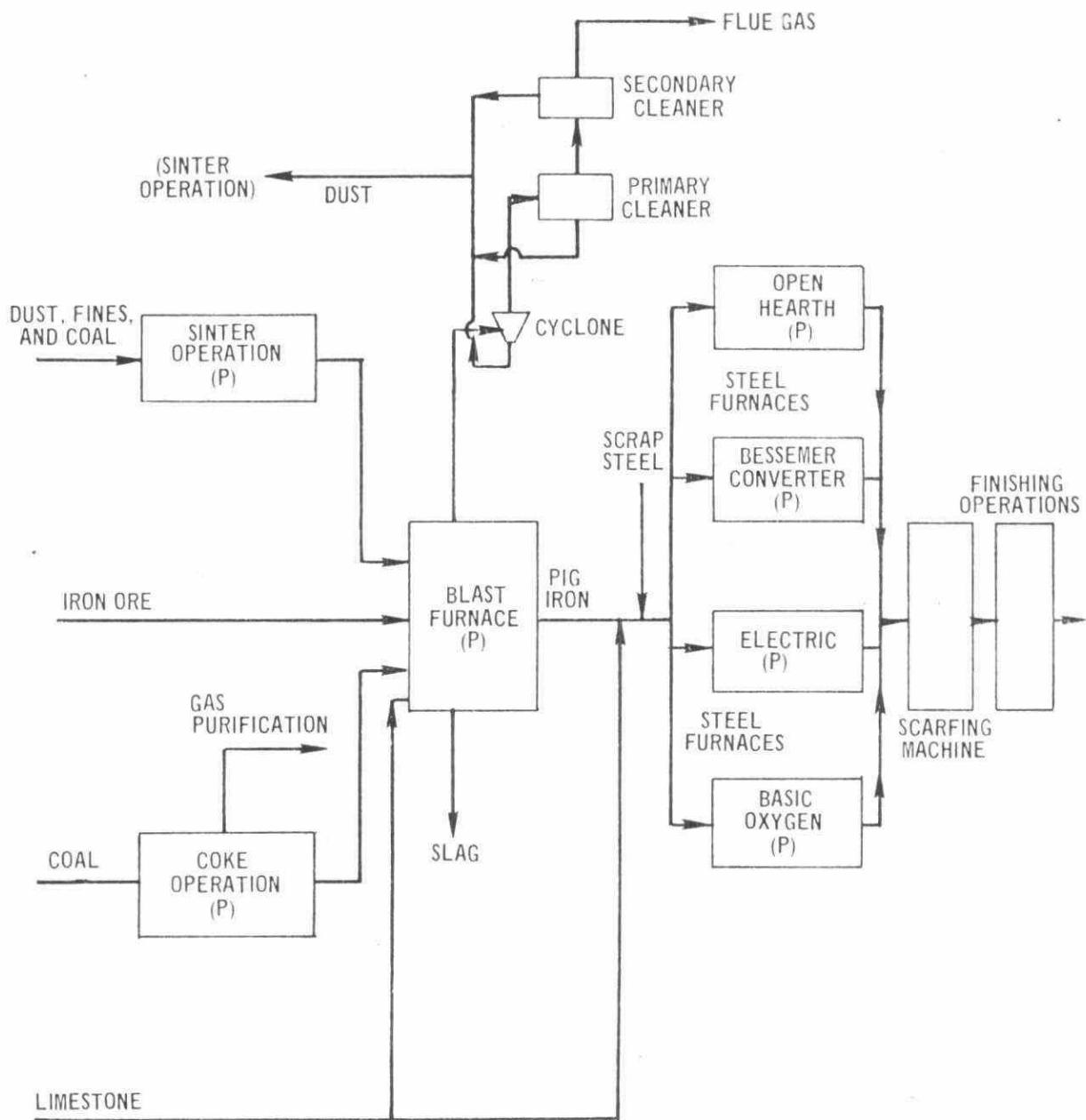


Figure 16-2 Basic flow diagram of iron and steel processes.
"P" denotes a major source of particulate emissions.

alloying elements include manganese, silicon, phosphorus, sulphur, aluminum, nickel, chromium, cobalt, molybdenum, vanadium, and copper.

Carbon steel, in which no minimum content is specified or required for any element added to obtain desired alloying effect, is the highest tonnage product.

Alloy steel is so classified when the content of alloying elements exceeds certain limits or in which a definite range of alloying elements is specified. The term "alloy steel" is not sufficient to cover certain other classifications such as stainless steel, tool steel, specialty steel, and others, although those steels do indeed contain specified amounts of alloying elements.

High strength, low alloy steels comprise a group with chemical compositions specially developed to impart better mechanical properties and greater resistance to atmospheric corrosion than are obtainable from conventional carbon structural steels.

Stainless and heat resisting steels obtain their inherent values by the addition of the element chromium to alloys of iron and carbon. Other elements also increase the corrosion resistance of steels, but the iron-chromium and iron-chromium-nickel steels are most important in the overall classification.

Steel is made from pig iron and scrap steel by oxidizing the impurities, reducing the iron oxides to iron, and adding the desired alloying constituents. The two common steel-refining processes are:

1. The basic process, wherein oxidation takes place in combination with a strong base, such as lime.
2. The acid process, wherein oxidation takes place without the base addition.

The two processes have the common purpose of removing the undesirable elements in the metal by the chemical reaction of oxidation reduction. Depending upon the alloy being

produced, the elements removed from a melt may be silicon, sulphur, manganese, phosphorus, or carbon. These elements are not removed by direct chemical reaction but by direct reaction.

For a basic refining process, limestone is added as a flux, and iron ore or mill scale as an oxidizing agent.

Steel-refining processes are usually accomplished in the Bessemer converter, the top-blown oxygen converter, the open-hearth furnace, or an electric furnace.

Bessemer or Converter Process

16.6 This method of steel manufacture, now relatively little used, consists of blowing, by mechanical means, a blast of air through liquid pig iron contained in a vessel. The oxygen burns up some of the impurities in the iron, generating intense heat, which keeps the iron molten. The oxides formed combine chemically to form a fluid slag on top of the molten iron. During the blowing, particles of this slag and metal sparks are ejected white hot from the converter mouth, giving the characteristic pyrotechnic display of the Bessemer process.

The vessel itself is known as a converter and comprises a mild steel casing lined with refractory material. It is pear-shaped, mounted on trunnions, and easily tilted for charging and pouring. Molten pig iron may be charged directly into the converter, otherwise it is first melted together with steel scrap, coke, limestone, and a little fluorspar, in a cupola.

In large plants, a receiver or mixer is frequently employed as an intermediate stage between cupola and converter. The mixer is a large receptacle or furnace into which the molten pig iron from the cupola is periodically run, and from which the converter is fed. A certain oxidation of manganese and silicon takes place in the mixture, which holds hundreds of tons of metal.

During the "blow" in the converter the first excess impurities removed by the oxidation of the blast are silicon, carbon, and manganese, in that order. When the carbon flame drops, blowing continues for 3 to 5 minutes, in which time the phosphorus and some sulphur are eliminated.

As all carbon has been blown off, the iron is recarburised by adding alloys of iron, carbon, and manganese, known as spiegel and ferro-manganese. After the blow the converter is turned down and as much slag as possible run off. The alloys are then added before pouring into the ladle.

Typical analyses:

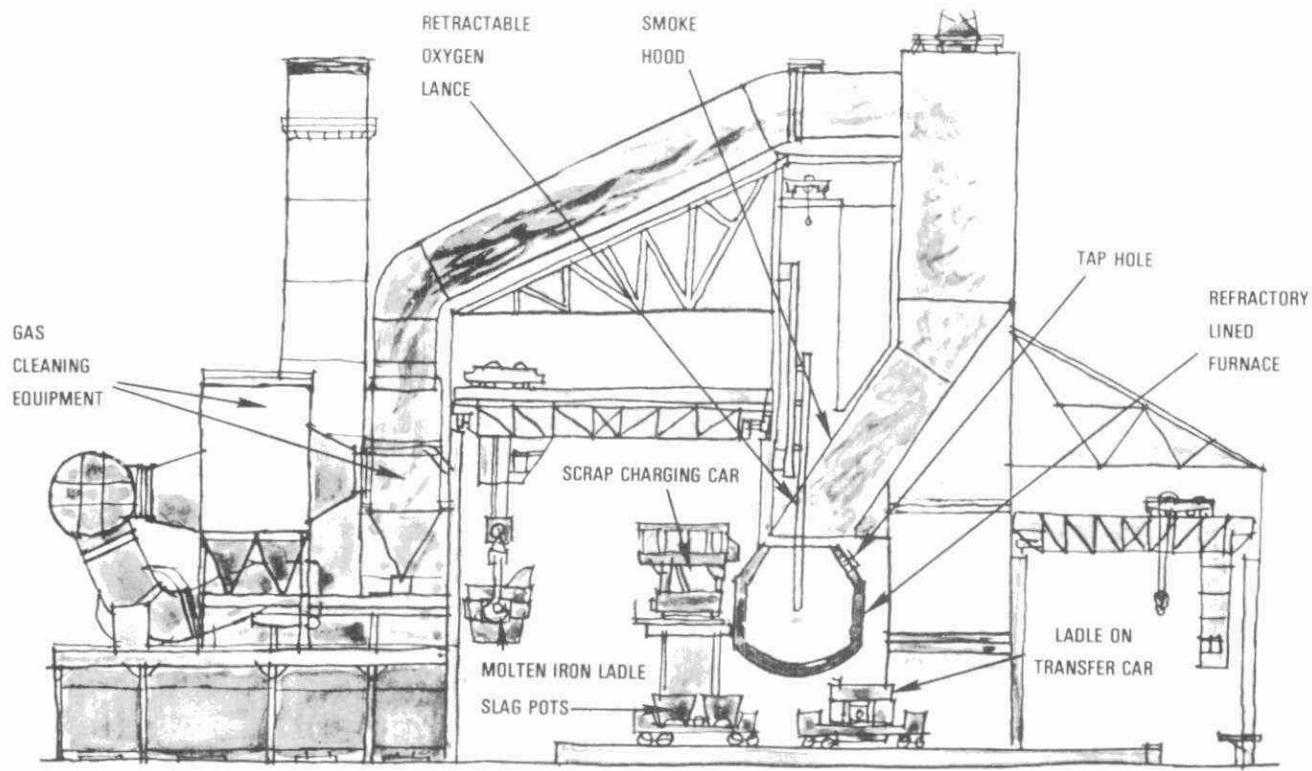
Pig Iron: -	3.5% carbon	Mild Steel -	0.15% carbon
	0.85% silicon		0.03% silicon
	0.08% sulphur		0.05% sulphur
	1.5% phosphorus		0.05% phosphorus
	1.0% manganese		0.5% manganese

Emissions from the Bessemer Converter

16.7 In the operation of the ordinary Bessemer converter there are two types of emission. Pellets of metal and slag are mechanically ejected due to the violence of the air blast bubbling through the molten metal. These are known as "spittings", composed of relatively coarse particles which tend to settle out on the premises close to the source. The other type is the visible brown-orange coloured fume of iron oxide, resulting from volatilization in the converter of some of the iron and subsequent oxidation in the open air during the "blow". These particles are suspended in the hot gases which, because of their buoyancy, rise to great heights transporting the visible fume with them.

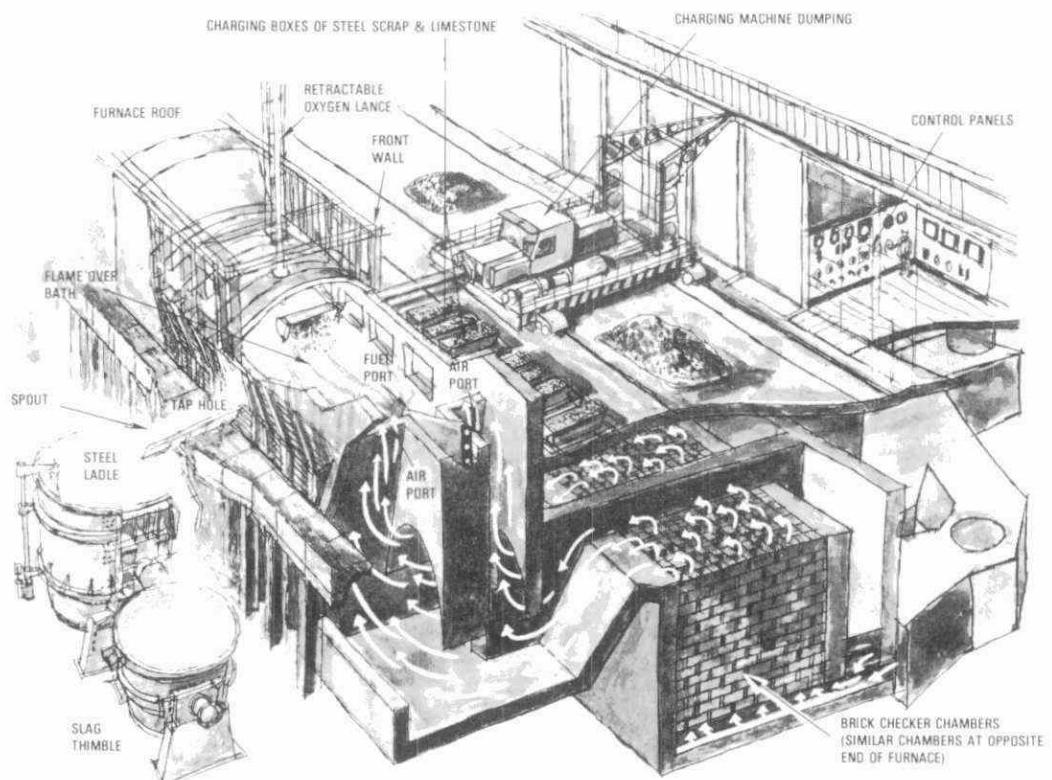
Basic Oxygen Furnace

16.8 A smelting process that is superficially similar to the Bessemer converter is the basic oxygen furnace (Figure 16-3) or the top-blown oxygen converter. It has now gained leadership over the traditional open hearth method, and may produce batches up to 300 tons in 45 minutes.



Schematic of a basic oxygen furnace shows the facilities needed to charge scrap and molten iron into the vessel and receive the steel after the oxygen blowing process is complete. Not shown are the chutes and bins which add fluxing materials to the vessel and alloying materials to the ladle of steel.

FIG. 16-3



Schematic of open hearth furnace shows sequential processes as simultaneous. Scrap steel and limestone are inserted in the hearth doors by charging machines. When materials melt, molten iron is added. Flames pass over the bath causing several unwanted elements to combine with limestone to form a slag. Oxygen is often injected to hasten the process.

FIG. 16-4
(Courtesy Steel Company of Canada Ltd)

The converter vessel in this process is similar to a Bessemer converter, but considerably larger than most of them. The principal difference is in the means for the supply of oxygen to the molten metal. Instead of bubbling air under pressure up and through the bath, a stream of oxygen is supplied through a water-cooled pipe extending from an overhead position downward into the converter, the end being positioned some distance above the surface of the bath. The high velocity of the oxygen impingement on the liquid metal surface results in violent agitation and intimate mixing of the oxygen with the molten pig iron. Rapid oxidation of the dissolved carbon and silicon, and some of the iron, ensues.

Emissions from the Basic Oxygen Furnace

16.9 The high concentration of oxygen results in the evolution of iron oxide fumes in considerably greater quantities than from the bottom-blown Bessemer converter, and in a correspondingly more objectionable emission.

Open-Hearth Process

16.10 The open-hearth furnace (Figure 16-4), the largest of the reverberatory furnaces, is the unit in which some 90% of steel used to be produced, prior to the development of big basic oxygen furnaces. In a process which is superficially simple but intrinsically rather complicated, the molten iron produced in the blast-furnace is transformed into steel by means which reduce the carbon content of up to 5% in the pig iron to a fraction of 1% and, equally essential in the modern steel making practice, controls the content of phosphorus, sulphur, manganese and silicon.

Groups of furnaces up to a dozen or so, depending upon size, arranged in a row comprise an open-hearth shop. The open-hearth shop is completely contained in a single building.

The furnace proper consists of a shallow rectangular basin or hearth enclosed by walls and roof, all constructed of refractory brick, and provided with access doors along one wall adjacent to the operating floor. A tap hole at the base

of the opposite wall above the pit is provided to drain the finished molten steel into the ladles. Fuel in the form of fuel oil, tar or gases is burned at one end. The flame from combustion of the fuel travels the length of the furnace above the charge resting on the hearth. The flame running across the top of the hearth oxidizes the impurities, and the process is continued until the desired level of carbon is reached. This is ascertained by regular sampling.

Today practically all open-hearth furnaces have been converted to the use of oxygen by means of retractable lances, so increasing temperatures and speeding up the melting process. The hot gases on leaving the furnace interior are conducted in a flue downward to a regenerative chamber, for heat recovery, consisting of a mass of refractory brick systematically laid to provide a large number of small passageways for the hot gas. In passing through the checkered brickwork the mass absorbs heat, cooling the gases to around 650° C.

All the elements of the combustion system - burners, checkerwork and flues - are duplicated at each end of the furnace, which permits frequent and systematic reversal of flow of the flame, flue gases and pre-heated air for combustion. A system of valves in the flue effects the gas reversal so that the heat stored up in the checkerwork is subsequently given up to a reverse direction stream of air flowing to the burners.

In some plants, the gases leaving the checkerwork pass to a waste heat boiler for further extraction of heat which reduces the temperature from around 650° C to an average of 260° to 315° C.

Open-hearth furnace capacities span a wide range. The median is between 10 to 200 tons per heat, but there are many of smaller capacity and an increasing number of larger capacity. Time required to produce a "heat" is commonly between 5 and 8 hours. A 350 tons furnace is about 90 feet long by 30 feet wide.

Raw materials charged to the open-hearth furnace besides pig iron include iron ore, limestone, scrap iron and scrap

steel; and each of these is employed in different forms. The pig iron may be molten or in the form of cold pigs. The iron ore may be fine or in lumps, and the scrap metal in a considerable variety of forms. The proportions of various ingredients vary with economic circumstances, with the characteristics of material supply, and numerous other factors that need not be detailed here. The proportioning of metals and auxiliary materials and the order and timing of their addition is complex, and dependent for example on the kinds of materials available, the kind of steel to be produced, characteristics of the fuel and of the furnace, and calls for a high order of skill from the open-hearth furnace operator.

Emissions from Open-Hearth Furnaces

16.11 The solids in the flue gases of open-hearth furnaces include both coarse and fine particles. They are continually emitted at highly variable rates throughout the 5 to 8 hour cycle of an open-hearth heat, and are variable in colour as well as quantity. These particles originate from the mechanical and chemical reaction of hot gases inside the furnace on the charged materials, from the chemical reactions and agitation in the molten bath itself, and from the combustion of the fuel. In addition to the dust and fume, gaseous emissions result in quantities determined by the composition and rate of fuel combustion.

Available data indicate that the highest rate of solids emission occurs in the first half hour after hot metal addition, and the period of 1 to 2 hours in the latter part of the ore boil. In the remaining period, the solids emission rate is materially lower. The overall average concentration of solids in the flue gases is approximately 0.4 grains per cubic foot measured at standard conditions. This amounts to approximately 5 to 10 pounds of solids per ton of steel dependent upon the type of furnace operation. Over half the dust is less than 1 micron in size and a large part of this material has been measured at about 0.03 micron.

Electric Furnaces

16.12 The function of electric furnaces was in general much more specialized than that of open-hearth furnaces and basic oxygen furnaces, in that they were specially adapted to the production of special alloy steels. However, with the development of electric furnaces which can average 300 tons per heat, they are now being used for high-tonnage production of carbon steels.

Major advantages of the electric furnace over fuel-fired furnaces are controlled furnace atmosphere and high-temperature operation. Temperatures as high as 3,300°^C are possible for special processes.

The types of electric furnace used are electric-arc, induction and resistance. The electric-arc furnaces may be either direct-arc or indirect-arc.

Electric-Arc Furnaces

16.13 The electric-arc furnace lends itself to accurate control of temperature and time of reaction for alloy composition. These advantages are achieved because no harmful gases are emitted from an electric arc that would otherwise produce an adverse effect upon the metal being refined. Steel may be produced in an arc furnace by either the basic or the acid process. The furnace may be charged with molten metal from an open-hearth furnace (an operation known as duplexing), or it may be charged with cold steel scrap. Owing to the close control that can be achieved, low-grade scrap can be refined to meet close specifications of the various steel alloys.

After the furnace has been charged with metal, fluxes and other additions required to accomplish the refining chemistry are charged according to schedule. The additions vary depending upon the steel being produced and the metal charged. Lime is usually a basic addition along with others, such as sand, fluorspar, iron ore, carbon, pig iron, and other alloying elements. The operation then continues in three phases:

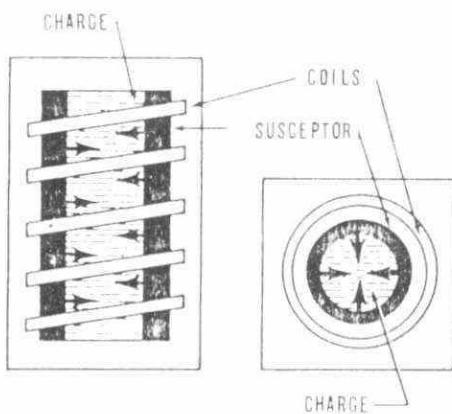
1. The oxidizing period, in which the undesirable elements are oxidized from the metal and removed as slag.
2. The reducing period, in which oxygen is removed from the metal mostly through the reaction with carbon.
3. The finishing period, in which additions are made to bring the alloy within the desired specifications.

Direct-Arc Furnaces (Figure 16-5)

16.14 In the direct-arc furnace, many and varied arrangements are used to heat the metal charged, but radiation between arc and the metal bath is the principal method. Here, the heat is generated by radiation from the arc as well as from the resistance heat effect within the bath. Graphite and carbon electrodes are usually used and are spaced just below the surface of the slag cover. The current passes from one electrode through the slag, the metal charge, the slag, and back to the other electrode. In some arrangements, the current is carried from the metal charge to the hearth. The slag serves a protective function by shielding the metal charge from vaporized carbon and the extremely high temperatures at the arc.

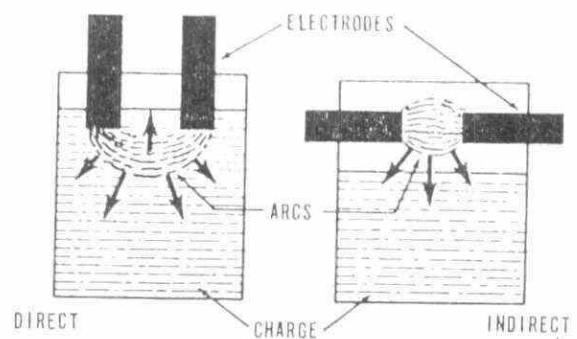
Indirect-Arc Furnaces (Figure 16-5)

16.15 In the indirect-arc furnace, the metal charge is placed below the electrodes, and the arc is formed between the electrodes and above the charge. One of the common smaller furnaces is the indirect-arc rocking furnace, in which an automatic rocking action of the furnace is employed to ensure a homogeneous melt. This is done by mounting the refractory-lined steel shell on cog bearings so that the furnace may be rocked through a 200° range. Radiated heat from the indirect-arc, and conduction from the pre-heated refractory lining initially melts small scrap, forming a pool of molten metal at the bottom of the furnace. Then the rocking action is initiated, and the molten metal washes against the refractory, picking up additional heat, which is transferred by convection and radiation to the larger pieces of metal.



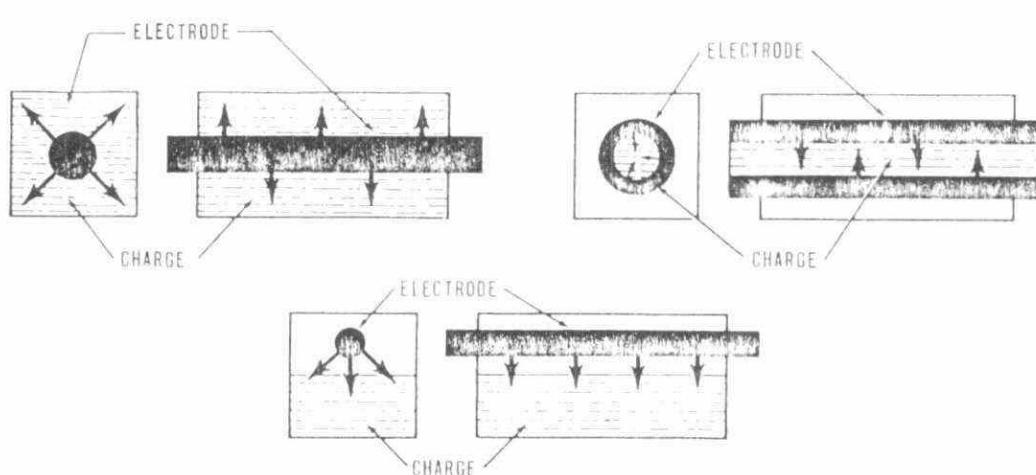
Principles of operation of an induction furnace
(Porter, 1959).

FIG. 16-6



Principles of operation
of two types of arc furnaces (Porter,
1959).

FIG. 16-5



Principles of operation of three types of resistance
furnace (Porter, 1959).

FIG. 16-7

Electric-Induction Furnace (Figure 16-6)

16.16 The induction furnace consists of a crucible within a water-cooled copper coil. An alternating current in the coil around the crucible induces eddy currents in the metal charge and thus develops heat within the mass of the charge, causing it to heat and melt. These furnaces range in size from 30 lb. to 8 tons capacity. They are not well adapted to a refining process and, for the most part, are used for the preparation of special alloys, or for certified true heats.

Resistance Furnace (Figure 16-7)

16.17 The resistance furnace is essentially a refractory-lined chamber with electrodes, moveable or fixed, buried in the charge. It is characterized by its simplicity of design and operation. The charge itself acts as an electrical resistance that generates heat. This type of furnace is used in the production of ferro-alloys (ferro-chrome, ferro-silicon, and others), cyanamide, silicon carbide, and graphite, and in hardening and tempering tools and machine parts.

Emissions from Electric Furnaces

16.18 During the melt-down stage, oxidizing conditions prevail and reactions occur that are similar to those in the bath of the basic open-hearth furnace. Although the differing characteristics of the two processes indicate differences in the mechanism of fume generation, they are not altogether dissimilar.

The quantity of escaping dust and fume has been variously estimated to range from 5 to 30 pounds per ton of steel melted, depending on size of furnace and the character of scrap as to its content of fine dirt.

Steel Treatment

16.19 At the end of the heat the molten steel is poured from the furnace in which it has been produced into a ladle, from which it is "teemed" into ingot moulds. When cool the cast iron mould is stripped off leaving an ingot of solid steel.

In order to be rolled each ingot must be brought to uniform temperature throughout. This is done in soaking pits - heated chambers equipped with automatic recording instruments and controls.

The size and shape of an ingot relates to the size of the roughing mill designed to handle it. Roughing mills produce semi-finished forms of steel such as blooms, which are roughly square in cross-section; slabs, which are rectangular in cross-section; and billets, which are smaller than blooms in cross-section and usually much longer.

If the steel is to be made into sheets or other flat products, the ingot is formed into a slab which will be further processed in the plate or hot strip mill. If it is to become bars, or wire rods, the ingot is formed into a bloom which is then further reduced in cross-section in the billet mill, as its length increases.

While most fabricated parts can be machined from forged or rolled blooms, billets, and bars, others are so intricate in shape and section that they have to be cast in sand moulds. Certain steels cannot be forged or rolled, and must be cast.

Wrought material begins its career as a simple shape which is brought to the desired form by working, either cold or hot, by rolling, forging, pressing, drawing, stamping, etc.

Rolling and Forging

16.20 The process of forging may be carried out under hammers or presses, the former ranging in size from a hand-sledge to large steam-hammers. For much of the heaviest forging, great hydraulic presses are used in which the heated metal is quietly pressed or kneaded into the desired shape. Forging, particularly on the large scale, is mainly applied to steel. Very large forgings are always made from the ingot itself, but for much small work the steel is first brought into bar form by rolling.

Stamping and pressing may also be regarded as alike to forging, but while true forging is always applied to a highly heated metal, stamping and pressing is done hot or cold.

While steel is always "broken down" hot, some of the softer non-ferrous metals and alloys can be safely treated cold. The essential nature of hot and cold rolling is the same, but cold rolling produces hardening, so that after a time the metal has to be "annealed" in order to soften it prior to further cold-rolling.

Annealing

16.21 This is a process of heating and cooling with the object of relieving stresses, or of altering the properties of the material. It is mainly used with castings, as annealing removes the stresses set up in cooling, and also refines the original coarse casting structure, but it is also used to soften materials hardened by cold working.

It consists of heating the metal slowly to about 960°C (steel), at which temperature it is held for several hours, depending on the mass of the metal. It is allowed to cool slowly, in the furnace, before removal.

Electricity, gas, and oil fired ovens are quite capable of working this process.

Normalizing

16.22 The metal is heated to about 960°C and allowed to cool in air. A finer crystalline structure than with annealing is produced, giving improved yield-point and tensile strength, but it cannot be used with castings having unusual variations of thickness as this may cause cracks.

Hardening (Quenching) and Tempering

16.23 This treatment is seldom given as it involves a risk of cracks due to rapid cooling and the unequal thicknesses of metal in castings. Where the metal is of almost uniform thickness, however, it can be employed with benefit.

The annealed casting is heated to a temperature of about 980°C, then quenched in water, oil, or a blast of air. This makes the steel very hard, but brittle, so it is tempered by

gently reheating to about 600°C then allowing it to cool in air. By this means the suppressed transformation of the structure, due to quenching, gradually takes place to a slight but progressive extent. This makes the steel tougher but softer.

Carburising (Case-Hardening)

16.24 Wrought iron or low-carbon steel is packed in carbonaceous material, such as a mixture of charcoal and barium carbonate, or charcoal and leather cuttings, in sealed boxes. These are heated to about 950°C and held at that temperature for 2 to 3 hours, depending on the extent of carburising required. The thickness and character of the metal surface is determined by duration, temperature, and carbonaceous compound used.

This process gives a carbon skin to the metal but is not a true hardening process.

A liquid sodium cyanide solution can be used to give a thin hard surface, afterwards being quenched in oil or water.

Heat Treatment Furnaces

16.25 Furnaces for heat treating are of all sizes and shapes, depending on the temperatures needed and upon the dimensions and the number of pieces to be treated. A furnace may be designed to operate continuously or batch-wise. The controls may be either automatic or manual. These furnaces are known by descriptive names such as box, oven, pit, pot, rotary, tunnel, muffle, and others. Regardless of the name the heat treatment furnace is a refractory-lined chamber in which material is placed for the purpose of heating. Its essentials are a combustion chamber, a furnace chamber, and a means of extracting flue gases, and its first function is to produce a satisfactory product.

The "stock" is heated by radiation and convection from flames and hot gases or electricity, and by radiation from the furnace linings. The composition of these gases is sometimes as important as their temperature, since the furnace

atmosphere may affect the stock. This is particularly so in the case of reheating and heat treatment furnaces. The atmosphere in which particular types of steel are heated must not impair the surface, or excessive oxidation and decarburization may occur, which can result in ultimate failure of the steel in use. The scale form may have to be of specific character to suit subsequent operations, e.g. rolling, or pickling. For this a "reducing" (oxygen free) atmosphere may be required.

The prevention of decarburization is essential to preserve the hardness and durability of cutting tools and to prevent premature fatigue and failure of stress parts.

The rate of scaling is governed primarily by temperature (hence low temperature treatment), then heating time, steel composition, and furnace atmosphere. Besides oxygen and steam, CO_2 and SO_2 all oxidize, forming scale. It can only be completely prevented by heating the charge in an inert atmosphere in a muffle furnace, as with bright annealing. The great thing to be avoided is a deeply-seated scale; so long as the scale is flakey it will break off during rolling.

Most oxidation defects in steel are caused by the presence of free oxygen in the treatment furnace atmosphere. For this reason, in order to avoid oxidization of stainless steel, this material is treated in an atmosphere of nitrogen, or in a vacuum.

Sintering Plants

16.26 Sintering machines are devices designed to convert iron ore fines and dust into a cake form suitable for charging into blast furnaces, by burning a mixture of this material with finely divided coke. Air for combustion is drawn through a flat porous bed of the mixture. The resulting high temperatures induce a condition of incipient infusion of the iron ore particles comprising the bed and results in formation of a firm porous bed.

The bed is formed on a slow moving grate composed of receptacle elements having perforated bottoms, known as

pallets. The pallets are linked end to end to form an endless metal belt with large sprockets at either end.

After the charge has been placed to form the bed, the coke in the mixture is ignited by playing flames on the surface. Air is induced down through the porous bed by means of exhaust fans connected to wind boxes underneath the top section of the pallet assembly. By this means combustion is maintained in a layer which slowly progresses downwards and is completed before any given portion of the bed arrives at the end of the machine. The red hot sintered mass breaks off at the end of the travelling grate and is reduced as cool air is drawn through it, frequently supplemented by water spray.

Emissions from Sintering Plants

16.27 There are two principal sources of dust in the operation of this process. One is in the combustion flue gases which contain some dust that has been mechanically entrained from the bed itself due to the passage of air through the material; this may also contain some fume due to volatilization of some of the constituents of the iron ore or dust in the mixture.

The other source of dust originates from the various stages in mechanical handling of the resultant sinter, during cooling, crushing, and screening processes.

The quantity of solids in flue gases varies with the type of ore and sintering machine design characteristics, but is probably in the same order of magnitude as that from a single open-hearth furnace of average capacity.

Coke Ovens

16.28 Metallurgical coke for smelting of iron ore in the blast furnace must meet particular specifications as to its physical qualities and composition, and it is specially produced in coke oven plants from carefully selected types of bituminous coal.

The wasteful and outmoded beehive coke oven which is operated occasionally in some districts during periods of high

demand for metallurgical coke, produces excessive amounts of smoke. Because of its inherent nature such smoke cannot be reduced and the only measure of control, therefore, is by restriction. The beehive coke oven is brick built, about 12 feet high, and 10 to 12 feet square. Each charge of fresh coal takes 72 hours to become carbonized to coke.

Most metallurgical coke today is produced in modern battery coke ovens (Figure 16-8). The selected coals are sized by crushing and pulverizing, blended according to formula, and transported to coal storage bins above the coke ovens. Measured quantities of the coal blend are removed from these bins into a larry car which runs on a track running along the top of the coke oven battery. The larry car then moves to an empty oven and its measured contents discharge into the oven interior.

A battery of coke ovens consists of individual ovens varying in width from 12 to 22 inches. A battery may include as many as 100 ovens side by side in a continuous structural unit. Each oven may be 30 to 40 feet long and up to 20 feet high, may take a charge of 15 to 20 tons of coal, and each cycle may take up to 15 to 22 hours at temperatures as high as 2,000°F.

During the coking cycle, volatile gases released from the coke charge are conducted through a system of pipes to the by-product plant where, in a series of processes, constituents of value are recovered from the raw gases and the final stripped coke oven gas piped to other equipment and burned as fuel. At the end of the coking cycle, the coke formed in this carbonizing process is discharged from the oven into a quenching car which transports it to a quenching station where the incandescent mass is quenched with large quantities of water. After cooling the coke is transported to screening and crushing equipment.

Emissions

16.29 Visible smoke or other emissions from a coke oven plant originate from the following operations:



Dofasco's new No. 5 coke oven battery
consisting of 53 ovens and facilities for
the collection and treatment of waste gases
*(photo courtesy of Dominion Foundries and
Steel, Limited).*

FIG. 16-8

1. Charging of coal into the oven
2. Leakage during carbonization
3. Pushing the coke out of the ovens
4. Quenching the hot coke

In addition, there are in-plant problems such as coal dust arising from the grinding and blending of coal, and steam and dust at the coal wharf.

1. Charging the Oven

16.30 After an oven has been emptied of coke at the end of a cycle, it is refilled with a new charge of coal which may range in size from 3" lumps down to pulverized material, and since the oven interior is still at a high temperature, volatilization of gases from the coal begins at once and escapes to the exterior as visible clouds of yellow/brown smoke.

Considerable progress has been made in reducing the quantity of such smoke, partly in arrangements and practices for minimizing its escape from the interior, and partly in shortening the time required for charging.

One improvement includes facilities for aspirating gases from the interior of the oven during charging by means of steam jet aspirators in the ascension pipe elbow, whereas formerly it was the practice to seal off the oven interior from the gas-collecting main during charging. This resulted in the emission of enormous quantities of smoke during this period. A further improvement was the provision of two gas collecting mains, with a gas ascension pipe with a steam jet aspirator at each end of the oven. This halved the length of gas travel to the point of exit. Another improvement consists of a gas pressure equalizing main on the side opposite to the collecting main. The equalizing main serves simply to connect all ovens to each other through this main, providing an exit for gases through one of the nearby ovens which, due to its coking stage, is under lower pressure and can thus accommodate this gas.

Other methods under development include the use of a vacuum system to hold the smoke and gases in, and a closed system using pelletized coal.

Means to provide an enclosure between the hopper of the larry car and the top of the charging oven, to prevent the escape of smoke-laden gases from the oven interior during the charging, may also be used. It may take the form of drop sleeves and shear gates, which allow the operator to lower the sleeve to the top of the oven preparatory to charging the coal, and to close the gate of each hopper as soon as it has been emptied.

Any arrangements which reduce the time required for transfer of the coal charge from larry car to interior will reduce the total escape of smoke, and a number of mechanical devices have been used to achieve this.

2. Carbonization Period

16.31 During this period leakage of smoke from the interior of an oven may occur around the doors unless measures are adopted to minimize it. In older designs the joint between the coke oven door and the jam was sealed by hand with a mixture of clay and coke breeze. In more recent years a number of self-sealing door designs have appeared in which metal-to-metal contact is achieved, but they require a regular maintenance program.

3. Discharging

16.32 At the end of the coking cycle, the incandescent coke is discharged from the oven into the coke-quenching car by means of a mechanical ram. During transport to the quenching station incompletely carbonized coke gives rise to considerable quantities of smoke, but if thoroughly carbonized very little smoke is produced.

4. Quenching

16.33 At the quenching station the car-load of incandescent coke, as much as 14 tons, is quenched with some 4,000 to 6,000

gallons of water in a period of about 90 seconds. Vast clouds of steam result. Most water droplets and any entrained particles of coke tend to be deposited on the ground within a short distance of the tower. Quenching is not, therefore, a significant source of air pollution.

IRON CASTING

16.34 Cast iron is a general term applicable to a group of iron-carbon alloys containing between 2 and 6 per cent carbon (usually 4.5 per cent is the allowable upper limit) and a small amount of silicon, sulphur, manganese, and phosphorus. Cast iron is inferior to steel in ductility, malleability, strength, and toughness, but low cost and ease of casting due to fluidity make cast iron popular for many parts. The types of cast iron commonly produced are:

1. White cast iron
2. Grey cast iron
3. Malleable iron
4. Ductile cast iron

1. White Cast Iron

16.35 Hard and brittle, this cast iron is obtained when the iron is cast in a metal mould and cooled rapidly. The carbon remains distributed throughout the iron as "cementite", a carbide of iron. This cast iron is characterized by high resistance to abrasion and wear and is used for parts particularly subject to wear.

2. Grey Cast Iron

16.36 Grey cast iron is formed when the iron in the mould cools slowly, part of the carbon separating out as graphite. It is easily machined, being much softer and less brittle than white cast iron. By alloying with nickel, chromium, molybdenum, vanadium, and copper the tensile strength may be varied from 20,000 to 90,000 psi.

3. Malleable Iron

16.37 Malleable iron is made by annealing white cast iron at about 1,700°F for several days. This changes the combined cementite carbon into free or "temper" carbon. The iron becomes more ductile and will withstand a greater shock load, as it is less brittle than cast iron. It also possesses greater tensile strength.

4. Ductile Cast Iron

16.38 Ductile cast iron is a high-carbon, magnesium-treated ferrous product containing spheroids of graphite. It is similar to grey cast iron in machinability, castability, and melting point, but it has superior mechanical properties.

Wrought Iron

16.39 Wrought iron is a form of iron with the impurities removed (ferrous sulphide and oxides of carbon, phosphorus, and silicon). It is relatively pure, containing only 0.1 to 0.2% carbon. Tough, malleable, ductile and corrosion-resistant, it melts at high temperatures. Wrought iron is used for rivets, bolts, and grate firebars, amongst other things.

Pig iron is converted to wrought iron by a process known as "puddling". The iron is heated in a reverberatory furnace, the impurities being oxidized and burned off. As the pig iron becomes purified its melting point rises so that the purified iron is "pasty" at the end of the process. It is "puddled" (stirred) with a steel rod until a ball of iron collects on the end. This is wrought iron which is then pressed into a billet.

Furnace Types

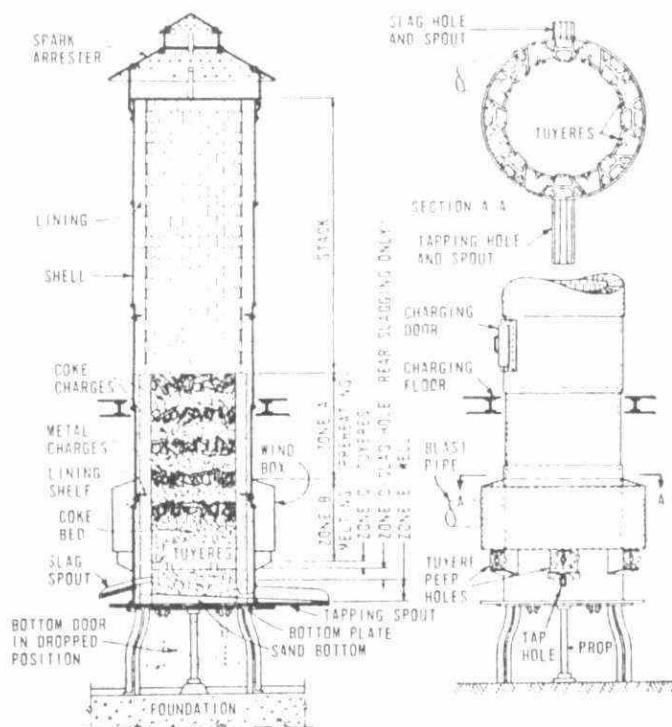
16.40 Control of the air pollution that results from the melting and casting of iron may be conveniently considered according to the type of furnace employed. The cupola, electric, and reverberatory furnaces are the types most widely encountered. The air pollutants are similar, regardless of

the furnace used; essentially, the air pollution problem becomes one of entraining the smoke, dust and fumes at the furnace and transporting these contaminants to suitable collectors.

The Cupola Furnace

16.41 The cupola furnace (Figure 16-9) is the most widely encountered piece of equipment in the grey iron industry. It is also used to melt or reduce copper, brasses, bronzes, and lead. High production rates are possible and production costs per ton of metal are relatively low. In addition to its high efficiency, the cupola is simple in its construction and operation. Despite this, where the product permits, some grey iron foundries have substituted reverberatory furnaces for their cupolas rather than install the air pollution control equipment that cupolas require.

The cupola is essentially a refractory-lined cylinder open at the top and equipped with air ports (known as tuyeres) at the bottom. Air is supplied from a forced-draught blower. Alternate charges of scrap or pig iron, coke and limestone are placed on top of the burning coke bed to fill the cupola. The heat generated melts the metal, which is drawn off through a tap hole. The principal dimensions of the cupola are its diameter and operating height (charging door to tuyeres). The diameter determines the melting capacity, and the height affects the thermal efficiency. The control of air at the tuyeres influences production rates, costs, metal losses, coke ratios, stack temperature, physical properties of the metal, and volume of stack emissions. Air is required, not only to furnish oxygen for the combustion of coke, which supplies the heat required for melting the iron, but also to aid in the potential combustion of the carbon, silicon, and manganese in the metal. Combustion air may be provided by a positive displacement type blower or a centrifugal blower. The quantity of air theoretically required is determined primarily by the size of the cupola, the melting rate, the metal-coke ratio, and the metal temperature. The actual air supplied may be increased as much as 15% to compensate for leakage.



A cupola furnace (American Foundrymen's Association, 1949).

FIG. 16-9

Automatic controls are frequently installed to maintain a constant weight flow of air.

Various methods of charging materials into the cupola are used. The smaller cupolas are frequently charged by hand while larger units may be charged with skip hoists with various types of cars, buckets, trains, or trolleys. Charging and melting is a continuous operation.

In order to increase the efficiency of a cupola, various methods are used for pre-heating combustion air. This may be done by some means of heat exchange or by use of a separate external heater.

Emissions from Cupolas

16.42 Air contaminants emitted from cupolas are: 1) gases, 2) dust and fumes, and 3) smoke and oil vapour. The following is a typical cupola combustion gas analysis:

CO ₂	12.2%	CO	11.2%	O ₂	0.4%	N	76.2%
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20% to 30% by weight of the fumes are less than 5 microns in size.

Dust in the discharge gases arises from dirt on the metal charge and from fines in the coke and limestone charge. Smoke and oil vapour arise primarily from the partial combustion and distillation of oil from greasy scrap charged to the furnace.

Electric-Arc Furnaces

16.43 Electric-arc furnaces are commonly used in the secondary melting of iron where special alloys are to be made. These furnaces may be either the direct or indirect-arc types (Figure 16-5). Pig-iron and scrap iron are charged to the furnace and melted, and alloying elements and fluxes are added at specified intervals. These furnaces have the advantage of rapid and accurate heat control.

Emissions from Electric-Arc Furnaces

16.44 Since no gases are used in the heating process, some

undesirable effects on the metal are eliminated. Since arc furnaces in the iron industry are virtually always used to prepare special alloy irons, the quality of the material charged is closely controlled. The charging of greasy scrap, which would emit combustible air contaminants, would only needlessly complicate the alloying procedure. The emissions consist, primarily, of metallurgical fumes varying according to the process from 5 to 10 pounds per ton of metal processed.

Induction Furnaces (Figure 16-6)

16.45 Core-type electric-induction furnaces are also used for melting cast-iron, and generate considerably smaller amounts of air contaminants than the cupola or the electric-arc furnace. Dirty scrap, however, or the addition of magnesium for manufacturing ductile iron would necessitate control equipment.

Reverberatory Furnaces

16.46 Small reverberatory furnaces are also used in preparing cast-iron alloys. If clean metal is charged to these furnaces, no excessive air pollution results from their use.

Core Ovens

16.47 Other possible sources of particulates at foundries are the core ovens which bake the cores used in the sand moulds. The cores contain binders that require baking to develop the strength needed to resist any erosion and deformation when the molten iron is poured into the mould. Sometimes, when special binders are used in the core, the ovens will emit fine aerosols that can have excessive opacities and cause eye irritation. Normally, an afterburner can control these contaminants.

SUBJECT:

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

TOPIC: 17

NON-FERROUS SMELTING
PROCESSES

OBJECTIVES:

The trainee will be able to:

1. Explain what emissions are to be expected from the following processes, and why:
 1. Secondary brass and bronze melting
 2. Secondary zinc melting
 3. Secondary aluminum melting
 4. Aluminum sweating;
2. Explain why fluxes are used in secondary aluminum melting, and the purpose of the following specific fluxes:
 1. Cover fluxes
 2. Solvent fluxes
 3. Degassing fluxes
 4. Magnesium fluxes.

NON-FERROUS SMELTING PROCESSES

17.1 A foundry is a place where products are cast from sand or permanent moulds. The separation of ingots of each element from scrap is termed "secondary melting". The preparation of alloy ingots from scrap is termed "secondary ingot production". Primary smelting only relates to the smelting of ore to obtain metallic elements.

For our purposes we will be discussing secondary melting and ingot production.

Secondary Brass and Bronze - Melting Processes

17.2 Copper when alloyed with zinc is usually termed brass, and when alloyed with tin is termed bronze. Other copper alloys are identified by the alloying metals such as aluminum bronze, and silicon bronze. The bronzes should not be confused with some other common classifications of bronzes which are actually misnomers. For example, "commercial bronze" is a wrought red brass, and "manganese bronze" is a high zinc brass. Because of high strength, workability, corrosion resistance, colour, and other desirable physical characteristics, the copper-base alloys have found wide use for hardware, radiators, condensers, jewellery, musical instruments, plumbing fittings, electrical equipment, ship propellers, and many other devices.

17.3 The remelting of nearly pure copper and bronze does not have great interest from the standpoint of air pollution since only small amounts of metal are volatilized. This is due to the high boiling points of copper and tin (above 2200°C) and their low

normal pouring temperatures of about $1,100^{\circ}$ to $1,200^{\circ}\text{C}$. With good melting practice, total emissions to the air should not exceed 0.5% of the process weight.

17.4 The brasses containing 15 to 40% zinc, however, are poured at temperatures near their boiling points (about $1,200^{\circ}\text{C}$), and some vaporization or combustion of desirable elements, particularly zinc, is inevitable (zinc boils at 907°C). Emissions into the air may vary from less than 0.5% to 6% or more of the total metal charged and 2 to 15% of the zinc content through fuming, depending upon the composition of the alloy, the type of furnace used, and the melting practice. Since the metal must be heated to melt the copper, which has the highest pouring temperature, a portion of the zinc will be brought to its boiling point and will volatilize.

17.5 Brass and bronze shapes for working, such as slabs and billets, are usually produced in large gas and oil-fired furnaces of the reverberatory type. Most operators of secondary smelters also use this type of furnace for reclaiming and refining scrap metal, ordinarily casting the purified metal into pigs. Brasses and bronzes used to make commercial castings are usually melted in low-frequency induction furnaces in the larger foundries and in crucible type, fuel-fired furnaces in the smaller job foundries. Electric furnaces, both arc and induction, are also used for castings.

Emissions

17.6 Generalizing in regard to the emissions from various furnaces is difficult, since foundry practices are variable. Air contaminants emitted from brass

furnaces consist of products of combustion from fuel, and particulate matter in the form of dusts and metallic fumes. The particulate matter comprising the dust and fume load varies according to the fuel, alloy composition, melting temperature, type of furnace, and many operating factors. In addition to the ordinary solid particulate matter, such as fly-ash, carbon, and mechanically produced dust, the furnace emissions generally contain fumes resulting from condensation and oxidation of the more volatile elements, including zinc, lead, and others.

17.7 Perhaps the best way to understand the difficulty of controlling metallic fumes from brass furnaces is to consider the physical characteristics of these fumes. The particle sizes of zinc oxide fumes vary from 0.03 to 0.3 micron. Lead oxide fumes, emitted from many brass alloys, are within the same range of particle sizes. The collection of these very small particles requires high-efficiency control devices.

17.8 In copper base alloy foundries up to 98% of the particulate matter in the furnace stack gases may be zinc oxide and lead. For practical purposes the weight of particulate matter from fuel-fired brass furnaces can be estimated quite safely at about 1% of the process weight entering the melt.

17.9 A U.S. report on the Air Contaminants Produced by Furnaces in the Non-ferrous Industry summarizes four principal factors causing high concentrations of zinc fumes in foundry furnace gases, as follows:

1. Alloy composition - the rate of loss of zinc will be approximately proportionate to zinc percentage in the alloy.

2. Pouring temperature - for a given percentage of zinc an increase of 38°C will increase the rate of loss of zinc about three times.
3. Type of furnace - direct fire furnaces will produce higher concentrations than crucible types, other conditions being equal.
4. Poor foundry practice - overheating of charge, addition of zinc at maximum temperature of furnace, use of insufficient covering of flux, etc.

Secondary Zinc - Melting Processes

17.10 Zinc is melted in crucible, pot, kettle, reverberatory, or electric-induction furnaces for use in alloying, casting, and galvanizing. Secondary refining of zinc is conducted in retort furnaces, which can also be used to manufacture powdered zinc by vaporizing zinc oxide by burning zinc in air. Two types of retort are illustrated in Figures 17-1 and 17-2.

17.11 The melting operation is essentially the same in all the different types of furnaces. Zinc to be melted may be in the form of ingots, reject castings, flashing, or scrap. Ingots, rejects, and heavy scrap are generally melted first to provide a molten bath to which light scrap and flashing are added. After sufficient metal has been melted it is heated to the desired pouring temperature, which may vary from 425° to 595°C . Before the pouring, a flux is added and the batch agitated to separate the dross accumulated during the melting operation. Dross is formed by the impurities charged with the metal and from

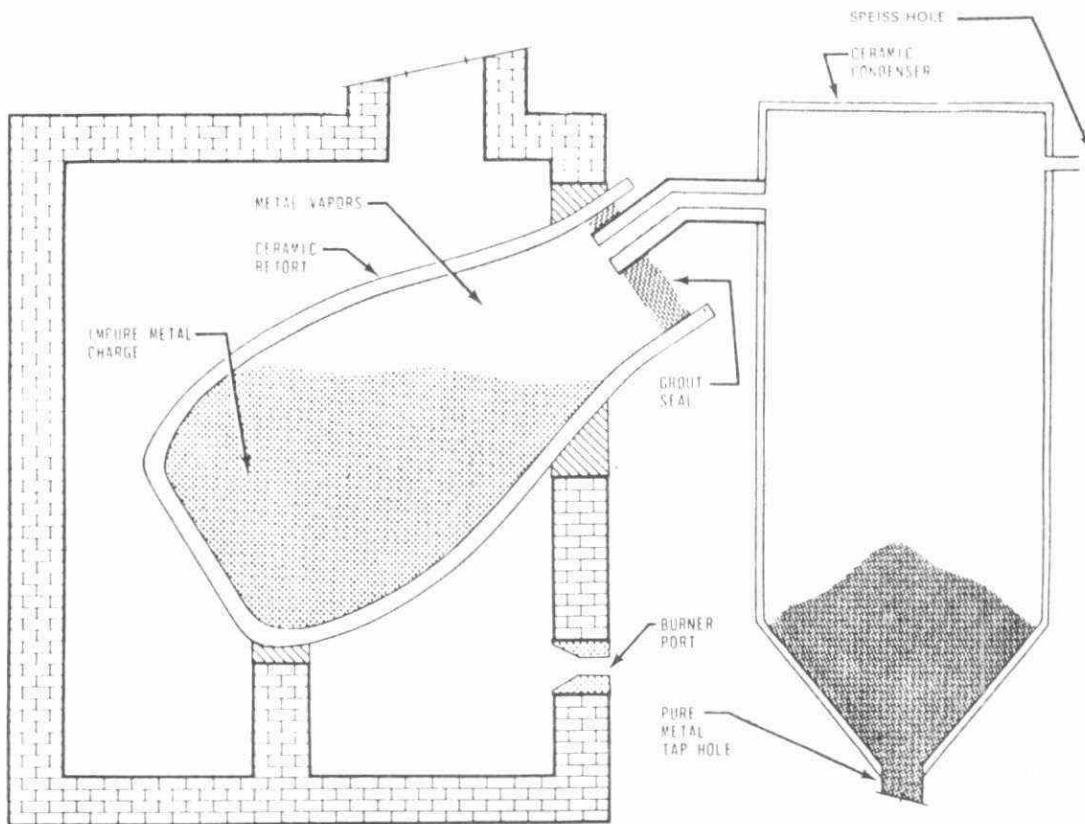


Diagram of a distillation-type retort furnace.

FIGURE 17-1

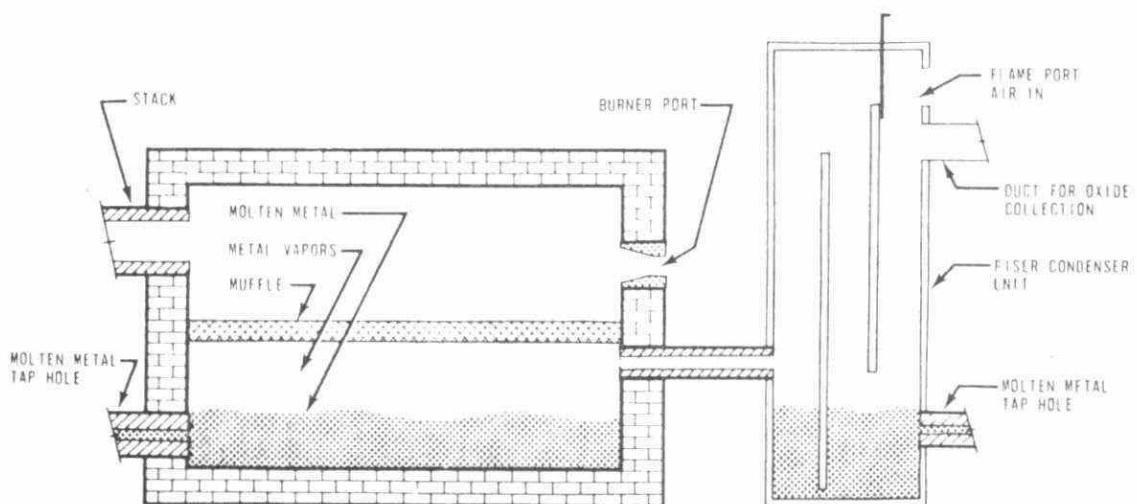


Diagram of a muffle furnace and condenser.

FIGURE 17-2

oxidation during the melting and heating cycles. The flux tends to float any partially submerged dross and conditions it, so that it can be skimmed from the surface. When only clean ingot is melted, very little, if any, fluxing is necessary. On the other hand, if dirty scrap is melted, large amounts of fluxes are needed. After skimming, the melt is ready for pouring into moulds or ladles.

Emissions

17.12 The discharge of air contaminants from melting furnaces is generally caused by excessive temperatures and by the melting of metal contaminated with organic material. Fluxing can also create excessive emissions, but fluxes are available that clean the metal without fuming.

17.13 Probably the first visible discharge noted from a furnace is from organic material. Before the melt is hot enough to vaporize any zinc, accompanying organic material is either partially oxidized or vaporized, causing smoke or oily mists to be discharged. This portion of the emission can be controlled either by removing the organic material before the charge into the furnace, or by completely burning the effluent in a suitable incinerator or afterburner.

17.14 Normally, zinc is sufficiently fluid for pouring at temperatures below 595°C. If the metal is heated above 595°C, excessive vaporization can occur and the resulting fumes need to be controlled with an air pollution control device.

17.15 Many fluxes now in use do not fume, and air contaminants are not discharged. In some cases, however, a specific fuming flux may be needed, in which case a baghouse is required to collect the emissions. An example of a fuming flux is ammonium chloride, which, when heated to the temperature of molten zinc, decomposes into ammonia and hydrogen chloride gases. As the gases rise into the atmosphere above the molten metal, they recombine, forming a fume consisting of very small particles of ammonium chloride.

Secondary Aluminum - Melting Processes

17.16 Secondary aluminum melting is essentially the process of remelting aluminum, but the term encompasses the following practices:

1. Fluxing.

This term is applied to any process in which materials are added to the melt to aid in removal of gases, oxides, or other impurities, but do not remain in the final product.

2. Alloying.

This term is applied to any process in which materials are added to give desired properties to the product and become part of the final product.

3. Degassing.

This includes any process used to reduce or eliminate dissolved gases.

4. "Demagging".

This includes any process used to reduce the magnesium content of the alloy.

These terms are often used vaguely and overlap to a great extent. For example, degassing and demagging are usually accomplished by means of fluxes.

17.17 Aluminum for secondary melting comes from three main sources: 1) aluminum pigs, 2) foundry returns; and 3) scrap. The melting of clean aluminum pigs and foundry returns without the use of fluxes does not result in the discharge of significant quantities of air contaminants, but the melting of aluminum scrap frequently does.

17.18 For melting small quantities of aluminum, up to 1,000 lb., crucible or pot-type furnaces are used extensively. Small crucibles are lifted out of the furnace and used as ladles to pour into moulds. The larger crucibles are usually used with tilting-type furnaces.

17.19 The reverberatory furnace is commonly used for medium and large capacity heats. Reverberatory furnaces of 20 to 50 ton holding capacity are common. Usually one heat is produced in a 24 hour period, however, the time per heat in different shops vary from 4 hours to as much as 72 hours. After the charge is completely melted, alloying ingredients are added to adjust the composition to required specifications. Large quantities of fluxes are added when scrap of small size and low grade is melted. The flux in some cases may amount to as much as 30% of the weight of scrap charged.

17.20 Electric induction furnaces are becoming increasingly common for both melting and holding aluminum in spite of higher installation and operating costs. Most electric furnaces for aluminum melting are relatively small, though some holding furnaces have capacities up to 15 tons.

17.21 A few rotary type open flame furnaces are used by small operators for treating dirty scrap to produce aluminum pigs for remelting. These are revolving cylinders open at the high end and sloping steeply towards the lower, closed end. Scrap is charged into the open end and molten metal trickles from small openings in the lower end.

Fluxing

17.22 The quantity and type of fluxing depend upon the type of furnace, the materials being melted, and the specifications of the final product. A few operators melting only pigs and returns find fluxing unnecessary. At the other extreme are large secondary smelters that process low grade scrap and use large quantities of fluxes. Fluxes for degassing or demagging may be either solids or gases. The gaseous types are usually preferred because they are easier to use, and the rate of application is simple to control. Some of these, for example, chlorine, may be used for either degassing or demagging, depending upon the metal temperature. In general, any flux that is effective in removing magnesium also removes gas inclusions.

1. Cover Fluxes

17.23 Cover fluxes are used to protect the metal from contact with air and thereby prevent oxidation. Most of these fluxes use sodium chloride as one of the ingredients. Various proportions of sodium chloride are frequently used with calcium chloride and calcium fluoride. Sometimes cryolite, or cryolite with aluminum fluoride, is added to dissolve oxides. Borax has also been used alone and in combination with sodium chloride.

2. Solvent Fluxes

17.24 Solvent fluxes usually form a gas or vapour at the temperature of the melt. Their action is largely physical. The resulting agitation causes the oxides and dirt to rise to the top of the molten metal where they can be skimmed off. Included in this group are aluminum chloride, ammonium chloride, and zinc chloride. Zinc chloride increases the zinc content of the alloy. Aluminum chloride, which is formed in this reaction, is a vapour at temperatures above 178°C. It bubbles out of the melt, forming a dense white fume as it condenses in the atmosphere.

17.25 So-called chemical fluxes are solvents for aluminum oxide. Cryolite, other fluorides, or borax are used for this purpose. Part of the action of the fluorides is thought to be due to the liberation of fluorine, which attacks silicates and dirt. Some chlorides are also used extensively, but their action is not understood.

3. Degassing Fluxes

17.26 There are many methods of removing dissolved gas from molten aluminum, some of which do not require the addition of a flux. Among the non-flux methods are the use of vibration, high vacuum, and solidification with remelting. None is as effective as the use of an active agent such as chlorine gas. Helium, argon, and nitrogen gases have also been used successfully. Solid materials that have been used include many metallic chlorides. Some think that their action is physical rather than chemical and that one gas is as good as another. For this reason, nitrogen has been used extensively. It is not toxic and virtually no visible air contaminants are released

when it is used. In addition, it does not coarsen the grain or remove sodium or magnesium from the melt. The main objection to the use of nitrogen is that commercial nitrogen is usually contaminated with oxygen and water vapour.

4. Magnesium - Reducing Fluxes

17.27 The use of fluxes to reduce the magnesium content of aluminum alloys is a relatively new procedure. Certain fluxes have long been known to tend to reduce the percentage of magnesium in the alloy, but this process did not become commonplace until World War 2. Several fluxes may be used for this purpose. Aluminum fluoride and chlorine gas are perhaps the most commonly used. The temperature of the melt must be significantly greater in demagging than in degassing, usually between 760° to 815C.

17.28 As much as 1 ton of aluminum fluoride is commonly used in reverberatory furnaces of 40 to 50 ton capacity. The aluminum fluoride is usually added to the molten metal with small quantities of other fluxes, such as sodium chloride, potassium chloride, and cryolite, and the entire melt is stirred vigorously. Magnesium fluoride is formed, which can then be skimmed off. Large quantities of air contaminants are discharged from this process. Chlorine gas for this purpose is easier to regulate, but extra precautions must be taken because of the extreme toxicity of this material. The chlorine is fed under pressure through the tubes or lances to the bottom of the melt and permitted to bubble up through the molten aluminum.

Emissions

17.29 Boiling point temperatures of the major metal constituents are high, about $2,590^{\circ}\text{C}$ for silicon, $1,800^{\circ}\text{C}$ for aluminum, and $1,100^{\circ}\text{C}$ for magnesium. Most alloys probably boil at considerably lower temperatures but still high enough, that with care, the losses of metals by fuming are not great. Much of the fume from aluminum-alloy furnaces consists of volatile elements contained in fluxes, or formed in reactions in the melt. Frequently, a large part of the material charged to a reverberatory furnace is low-grade scrap and chips. Paint, dirt, oil, grease, and other contaminants from this scrap cause large quantities of smoke and fumes to be discharged. Even if the scrap is clean large surface-to-volume ratios require the use of more fluxes, which can cause serious air pollution problems.

17.30 In a study of the extent of visible emissions discharged from degassing aluminum with chlorine gas, the major parameters were found to be metal temperature, chlorine flow rate, and magnesium content of the alloy. Other factors affecting the emissions to a lesser degree are the depth at which the chlorine is released and the thickness and composition of the dross on the metal surface.

17.31 When chlorine is used for demagging, it is added so rapidly that large quantities of both aluminum chloride and magnesium chloride are formed, the molten bath is vigorously agitated, and not all of the chlorine reacts with the metals. As a result, a large quantity of aluminum chloride

is discharged along with chlorine gas and some entrained magnesium chloride. The aluminum chloride is extremely hygroscopic and absorbs moisture from the air, with which it reacts to form hydrogen chloride. These air contaminants are toxic, corrosive, and irritating.

Metal Separation Processes

17.32 In addition to the metallurgical processes previously mentioned, there are other processes classified as metal separation that can be troublesome from an air pollution standpoint. In these, the metal desired is recovered from scrap, usually a mixture of several metals. Probably the most common of these processes, aluminum sweating, is the recovery of aluminum from aluminum drosses and other scrap. Other examples of metal separation processes include the recovery processes for zinc, lead, solder, tin, and low-melting alloys from a host of scrap materials.

Aluminum Sweating

17.33 Open-flame, reverberatory-type furnaces are used by secondary smelters to produce aluminum pigs for remelting. These furnaces are constructed with the hearth sloping downwards towards the rear of the furnace. All types of scrap aluminum are charged into one of these furnaces, which operate at temperatures of 680° to 760°C. In this temperature range, the aluminum melts, trickles down the hearth, and flows from the furnace into a mould. The higher melting materials such as iron, brass and dross oxidation products formed during melting remain within the furnace. This residual material is periodically raked from the furnace hearth.

17.34 Some large secondary aluminum smelters separate the aluminum suspended in the dross by processing the hot dross immediately after its removal from the metal in the refining furnace. The hot dross is raked into a refractory-lined barrel to which salt-cryolite flux is added. The barrel is placed on a cradle and mechanically rotated for several minutes. Periodically, the barrel is stopped and the metal is tapped by removing a clay plug in the base of the barrel. This process continues until essentially all the free aluminum has been drained and only dry dross remains. The dross is then dumped and removed from the premises.

17.35 The aluminum globules suspended in the dross as obtained from the hot dross process can also be separated and reclaimed by a cold, dry, milling process. In this process large chunks of dross are reduced in size by crushing and then fed continuously to a ball mill where the oxides and other non-metallics are ground to a fine powder, which allow separation from the larger solid particles of aluminum. At the mill discharge, the fine oxides are removed pneumatically and conveyed to a baghouse for ultimate disposal. The remaining material passes over a magnetic roll to remove tramp iron and is then discharged into storage bins to await melting. This process is used primarily to process drosses having a low aluminum content.

Zinc, Lead, Tin, Solder, and Low-Melting Alloy
Sweating

17.36 Although recovery of aluminum is the most common of the metal separation processes, others

that contribute to air pollution deserve mention. These include, zinc, lead, tin, solder, and low-melting alloy sweating. Separation of these metals by sweating is made possible by the differences in their melting point temperatures. Some of these melting temperatures are:

Tin	232° ^C
Lead	327° ^C
Zinc	419° ^C
Aluminum	660° ^C
Copper	1,084° ^C
Iron	1,535° ^C

17.37 When the material charged to a sweating furnace contains a combination of two of these metals, it can be separated by carefully controlling the furnace temperature so that the metal with the lower melting point is sweated when the furnace temperature is maintained slightly above its melting point. After this metal has been melted and removed, the furnace burners are extinguished and the metal with a higher melting point is raked from the hearth.

17.38 Zinc can be recovered by sweating in a rotary, reverberatory, or muffle furnace. Zinc-bearing materials fed to a sweating furnace usually consist of scrap die-cast products, such as automobile grills, license plate frames, and zinc skims and drosses.

17.39 The sweating of lead from scrap and dross is widely practiced. Junk automobile storage batteries supply most of the lead. In addition, lead-sheathed cable and wire, aircraft tooling dies, type metal drosses, and lead dross and skims are also sweated.

The rotary furnace, or sweating tube, is usually used when the material processed has a low percentage of metal to be recovered. The reverberatory box-type furnace is usually used when the percentage of metal recovered is high.

17.40 Rotary and reverberatory furnaces are also used to sweat solder and other low-melting alloys from scrap metal. Automobile radiators and other soldered articles such as gas meter boxes, radio chassis, etc., make up the bulk of the process metal. For this recovery, the furnace is usually maintained between 345° and 370°C . Higher temperatures should be avoided to prevent the possible loss of other recoverable metals. For example, sweating automobile radiators at 480°C causes excessive oxidation of the copper.

Emissions

17.41 In theory, an aluminum-sweating furnace can be operated with minor emissions of air contaminants if clean, carefully hand-picked metals free of organic material is processed. In practice, this selective operation does not occur and excessive emissions periodically result from uncontrolled furnaces. Stray magnesium pieces scattered throughout the aluminum scrap are not readily identified, and charging a small amount of magnesium into a sweating furnace causes large quantities of fumes to be emitted. Emissions also result from the other materials charged, such as skims, drosses, scrap aluminum sheet, pots and pans, aircraft engines, plastic assemblies, etc.

17.42 Smoke is caused by the incomplete combustion of the organic constituents of rubber, oil and grease, plastics, paint, cardboard, and paper. Fumes result from the oxidation of stray magnesium or zinc assemblies and from the volatilization of fluxes in the dross. Sweating of dross and skims is responsible for the high rates of emission of dust and fumes. Residual aluminum chloride flux in the dross is especially troublesome because it sublimes at 178°C and is very hygroscopic. In addition, it hydrolyzes and forms very corrosive hydrogen chloride.

17.43 In the dry milling process, dust is generated at the crusher, in the mill, at the shake screens, and at points of transfer. These locations must be hooded to prevent the escape of fine dust to the atmosphere.

17.44 Emissions from zinc-sweating furnaces consist mainly of smoke and fumes. The smoke is generated by the incomplete combustion of the grease, rubber, plastic, etc. Zinc fumes are negligible at low furnace temperatures, for they have a low vapour pressure even at 480°C . With elevated furnace temperatures, however, heavy fuming can result.

17.45 Emissions from lead-sweating furnaces may be heavy with dust, fumes, smoke, sulphur compounds, and fly-ash. This is particularly true when junk batteries are sweated.

17.46 Contaminants generated during the sweating of solder, tin, and other low-melting alloys consist almost entirely of smoke and partially oxidized

organic material. The scrap metal charged is usually contaminated with paint, oil, grease, rust, and scale. Automobile radiators frequently contain residual anti-freeze and sealing compounds.

SUBJECT:

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

TOPIC: 18

OIL REFINERIES

OBJECTIVES:

The trainee will be able to:

1. Explain the following terms used in the basic processes of an oil refinery:

Distillation, conversion, treating, blending, cracking, reforming, polymerization, hydrogenation, hydrodesulphurization;

2. Explain the purpose and use of the flare;
3. State the sources of air contaminant emissions from a typical oil refinery and briefly describe how they can be controlled.

OIL REFINERIES

18.1 Crude oil is a mixture of thousands of different compounds, most of them liquids, but some gases and some solids. All the compounds in crude oil can be burned and, for this reason, crude oil is very useful as a source of energy. Many of the compounds are useful in other ways - as asphalt for roads, greases for machines, waxes for milk cartons, to name only a few. In refineries, crude oil is transformed to about 700 products, including some 50 waxes, 140 greases, 80 asphalts, 350 lubricating oils, assorted raw chemicals for use as petrochemicals, several grades of gasolines and a number of diesel, domestic, industrial and heavy fuel oils.

18.2 While individual refineries differ in the processes they use, generally every refinery uses four basic processes. In the first, the crude oil is separated into a number of parts, or "fractions". This is done by distillation. In the second process, certain of the fractions are changed into other and more useful compounds. To do this, the refineries change the chemical structure of the fractions. This is the conversion process. Nearly all the products that come from distillation, cracking and other major manufacturing processes contain small amounts of impurities. Some of these give the product a bad odour; others may cause rust or unnecessary wear. The job of removing these impurities and obtaining certain by-products is called treating, the third process. The fourth operation, blending, is the mixing together of different products and sometimes other materials so that the finished products will have all the qualities needed by consumers. A simplified flow diagram of a typical refinery is shown in Figures 18-1 and 18-2.

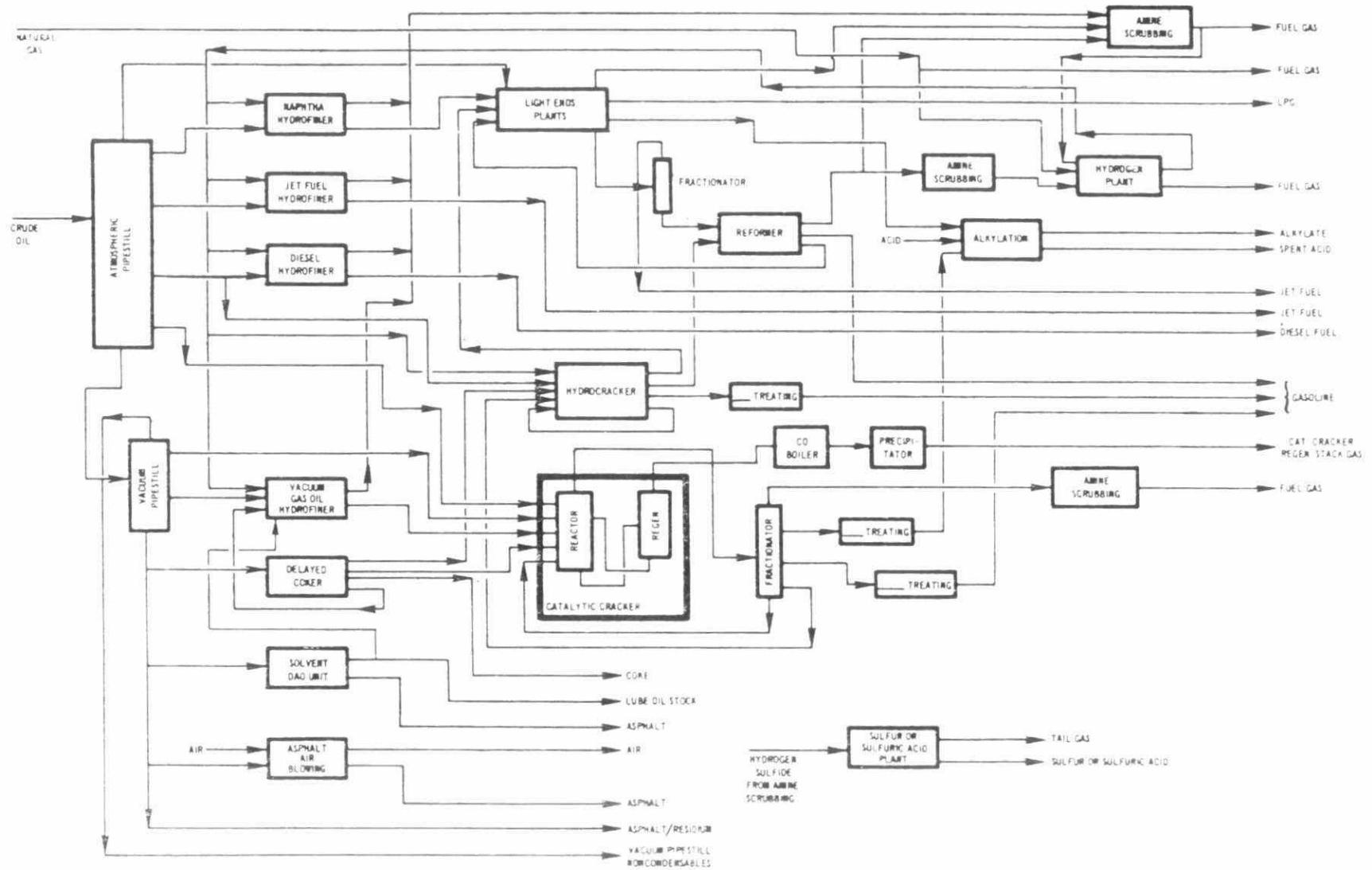


Fig. 18-1 Basic flow diagram of petroleum refinery.

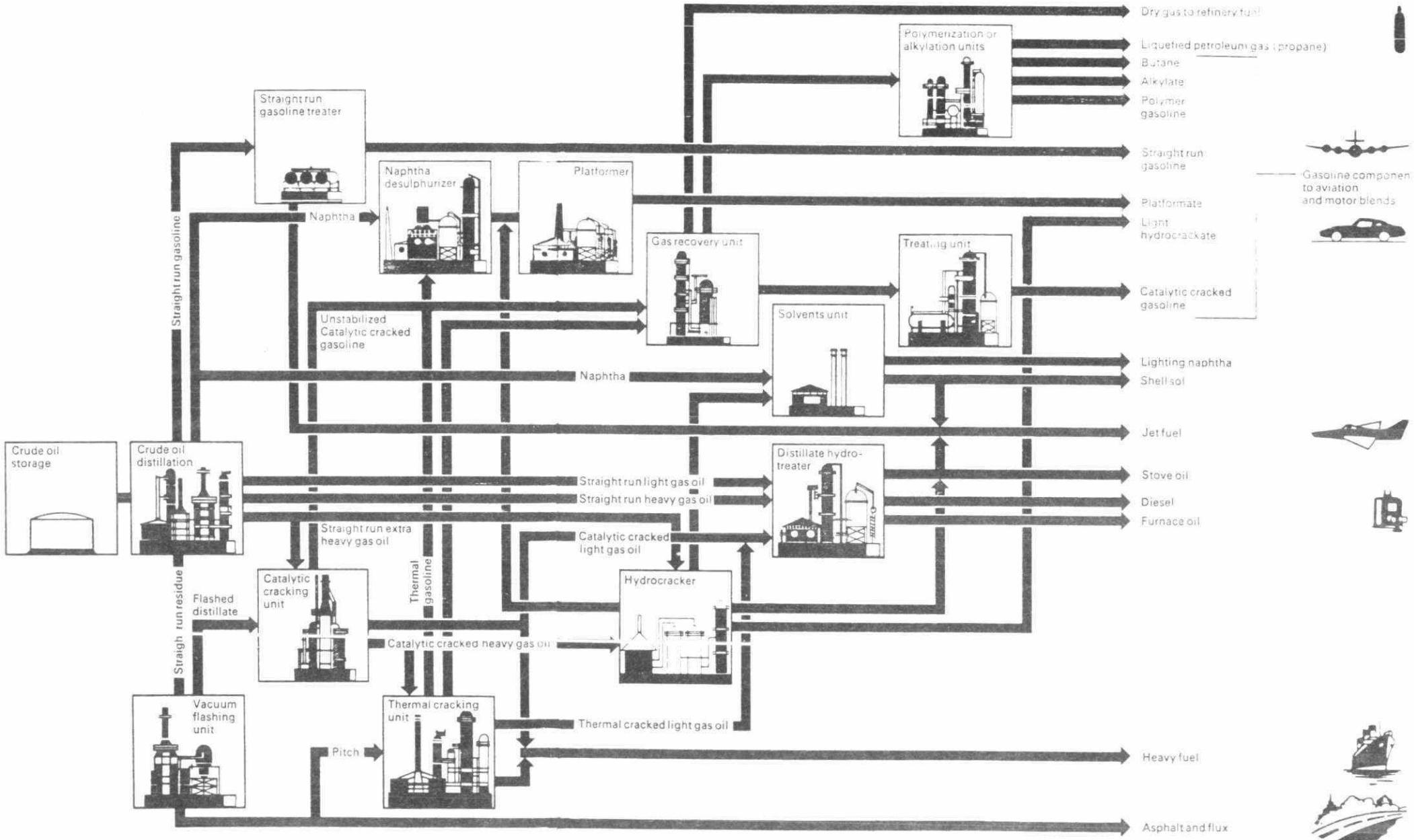


FIGURE 18-2 SIMPLIFIED FLOW DIAGRAM OF A TYPICAL REFINERY
(Courtesy of Shell Canada Limited)

1. Distillation

18.3 Crude oil is made up of many different substances, each of which boils and condenses at a different temperature. (The process of boiling and then condensing is called "distillation".) For instance, gasoline starts to boil at 32°C and condenses if it becomes cooler than that, but furnace fuel oil will not start to boil until it reaches 204°C , and it will condense whenever it is below that temperature.

Oil refineries make use of these characteristics of the substances in crude oil to separate them from each other.

They begin by heating the crude oil inside a furnace to about 345°C . At this temperature about 60 per cent of the crude oil changes to vapour. The vapours go to an atmospheric distillation tower. As the vapours swirl up inside the tower they begin to cool. Those which will condense at the lowest temperatures settle on trays near the top. Those which condense at higher temperatures settle in trays further down. These distillates range from gasoline at the top down through kerosene and diesel oil to fuel oil.

The unvapourized heavy residue at the bottom is pumped to the vacuum distillation unit. The vacuum permits the residue to boil at less than 345°C and be separated into further distillates ranging from vacuum gas oil at the top down through light lubricating oil and intermediate lubricating oil, to heavy lubricating oil, with a pitch residue at the bottom.

2. Conversion

(a) Cracking

18.4 In "cracking" - one of the main conversion processes - an oil fraction such as gas oil is heated under pressure. This causes its molecules to break down and literally "crack" to form smaller molecules of gasoline and light fuel oils. The process not only makes more gasoline from crude oil - it produces a better quality gasoline than that secured by distillation.

Cracking operations are carried out with the aid of a catalyst, which is a substance that helps a chemical process take place without being affected itself. The catalyst used in the cracking operation in many oil refineries is a fine powder (silica and alumina) - so fine that when it is mixed with air at high pressures it will flow through a pipe like a fluid. Thus this type of operation is called fluid catalytic cracking.

In cracking, the heavy oils are mixed with a hot catalyst and the resulting vapours flow with the catalyst to a reactor. The vapours crack into gases and gasoline, home heating oil, light industrial fuel oil and heavy industrial fuel oil, which are separated in a distillation tower. The catalyst becomes coated with carbon during the process. The used or "spent" catalyst goes to a "catalyst regenerator" where the carbon is burned off. The hot catalyst is re-circulated to mix with and vapourize more heavy oil.

(b) Reforming

18.5 Reforming gets its name from the fact that it changes the form or shape of gasoline molecules, cracking the hydrocarbons to increase octane rating, or to produce aromatics and paraffins from olefins in reforming, hydroforming or platforming units.

The gasoline comes from the distillation process. It is heated in a furnace, and the vapours piped to a tower. Inside the platforming tower is a catalyst which contains platinum. The catalyst is in the form of pills, a little smaller than aspirin tablets. A thick layer of the pills is supported on a screen. As the hot gasoline vapours pass through the catalyst, the shape of the molecules is changed.

Hydrogen is produced by the process and is usually burned in the furnace. In this way, the reforming process provides its own fuel and hydrogen for hydro-sulphurization. The catalyst, being unchanged itself, can be used over again.

(c) Polymerization

18.6 In polymerization smaller hydrocarbon molecules are joined together to produce larger ones.

As described earlier, the cracking operation produces light gases as well as other products. The polymerization process joins the molecules of some of these gases together to make molecules of the same size and shape as those of gasoline.

The gases are passed over a catalyst. Because of the nature of the gases and the catalyst and because of the conditions under which the process is carried on,

the small molecules of the gases are joined together to form gasoline molecules. The gasoline so formed is more powerful than that secured from the distillation process.

(d) Hydrogenation and Dehydrogenation

18.7 Altering the hydrocarbon structure by adding or removing hydrogen in hydrogenation and dehydrogenation units.

(e) Alkylation

18.8 Substituting or adding an alkyl group such as methyl or ethyl, so converting light gases, previously burned as waste fuel, into valuable aviation and motor gasolines.

(f) Isomerization

18.9 Rearranging molecular structure of hydrocarbon molecules without changing chemical formula to develop new properties in compounds.

3. Treating

(a) Lubricating Oils, Greases, Waxes and Asphalts

18.10 Compared to gasoline and fuel oils, lubricating oils and greases are used only in small quantities. For this reason only three of the 45 refineries in Canada make lubricating oils and greases as well as gasolines and fuel oils.

Refineries throughout the world have different ways of separating and treating lubricating oils to get

the products they want. Some of these are:

Phenol Treating

18.11 To make lubricating oils, refiners begin with a mixture of oils from the vacuum distillation unit. This mixture includes some oils that make good lubricants and some that do not.

The refiner's first job is to separate the good oils from the poor ones. He does this by a process called phenol treating. This process gets its name from the fact that it uses a form of carbolic acid called phenol. The phenol is mixed with the oil and the poor oils are dissolved in the phenol while the good lubricating oils are easily separated from it.

Solvent Dewaxing

18.12 Even after the oil mixture has been through the phenol treating plant, the good lubricating oils need further treating. One of the substances they still contain is wax which must be removed so that the oil will flow easily in cold weather. To remove the wax the oil is mixed with ketone. The oil dissolves in the ketone, and then the mixture is chilled. As the temperature drops, the wax becomes solid. Without the ketone the oil itself would become very thick and could not be separated from the wax. Because the oil-ketone mixture remains in liquid form, the wax can be separated out of it by filters. Later the oil is separated from the ketone.

Hydrodesulphurization

18.13 This is a relatively new process through which sulphur compounds are almost completely removed by passing oil over a catalyst in the presence of hydrogen. Elemental sulphur is recovered.

Greases

18.14 Most greases are made by mixing lubricating oil and soap. The soap holds the oil the way a sponge holds water. The two are mixed together in large kettles and heated until a properly blended grease results.

Wax

18.15 Earlier we saw how wax is removed from lubricating oils. This wax is eventually used in such familiar things as candles, waxed paper and cardboard milk cartons.

When the wax has first been separated from the lubricating oil (in the solvent dewaxing process), it still contains a small amount of oil. The oily wax is mixed with ketone. The oil in the wax dissolves in the ketone, the mixture is chilled, and the wax is filtered out. Later, the oil is separated from the ketone.

Asphalts

18.16 Asphalts for roads, shingles and other uses are made from the residue left in the bottom of the vacuum distillation tower. This residue can be used on roads without further processing. Harder asphalts that will

not run are needed for shingles. These are made by blowing air through the hot residue, causing it to harden gradually. The degree of hardness will depend on how much air is blown through.

4. Blending

18.17 Blending is the process of mixing or blending various petroleum fractions so that the final product will have all the qualities that will enable it to do its job properly.

Gasoline is a good example of a product that must be carefully blended. The gasoline made for use in cars, tractors and aircraft each need different qualities if they are to give top performance.

Gasolines are also blended to have different qualities in different seasons. In winter, for example, gasoline is blended in such a way that it will evaporate more easily.

When gasoline is blended other substances are added to it to improve its performance. Tetraethyl and tetramethyl lead are usually added to give more power and prevent the engine from knocking. A special oil is sometimes added to help protect the engine from wear. An "inhibitor" is often added so that the gasoline will keep well in storage.

AIR POLLUTION PROBLEMS AND CONTROL

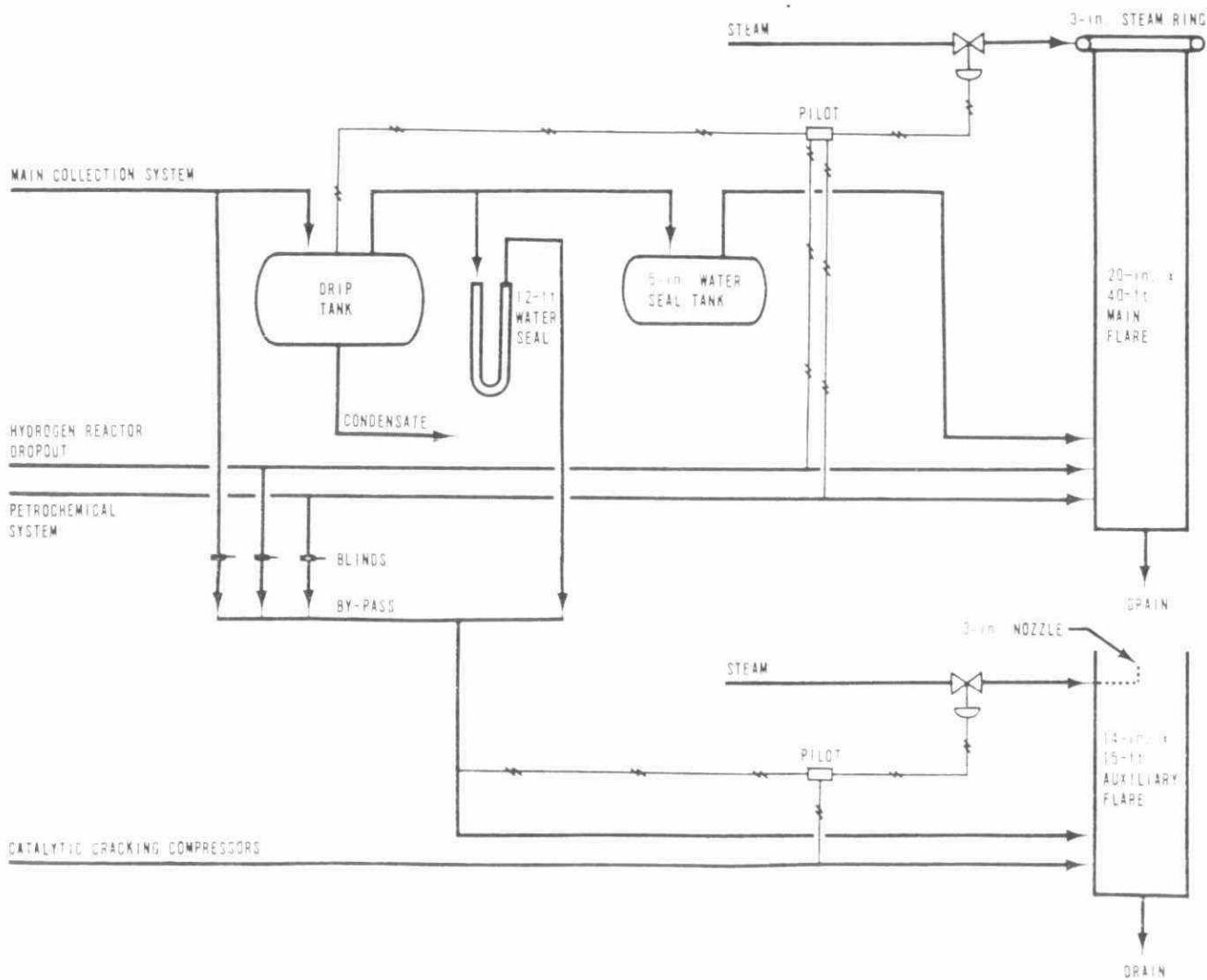
18.18 Petroleum stocks are extensively handled, treated, blended, stored, and marketed. Virtually every phase of petroleum production, recovery of waste products, refining and marketing, possesses pollution potentials, including emissions of saturated and unsaturated organic vapours, sulphur dioxide, hydrogen sulphide, oxides of nitrogen, carbon monoxide, catalyst dust, and visible smoke plumes. These may occur anywhere from the feeding and processing of stocks to the storage and handling of final products and the disposal of wastewater streams.

Flares and Blowdown Systems

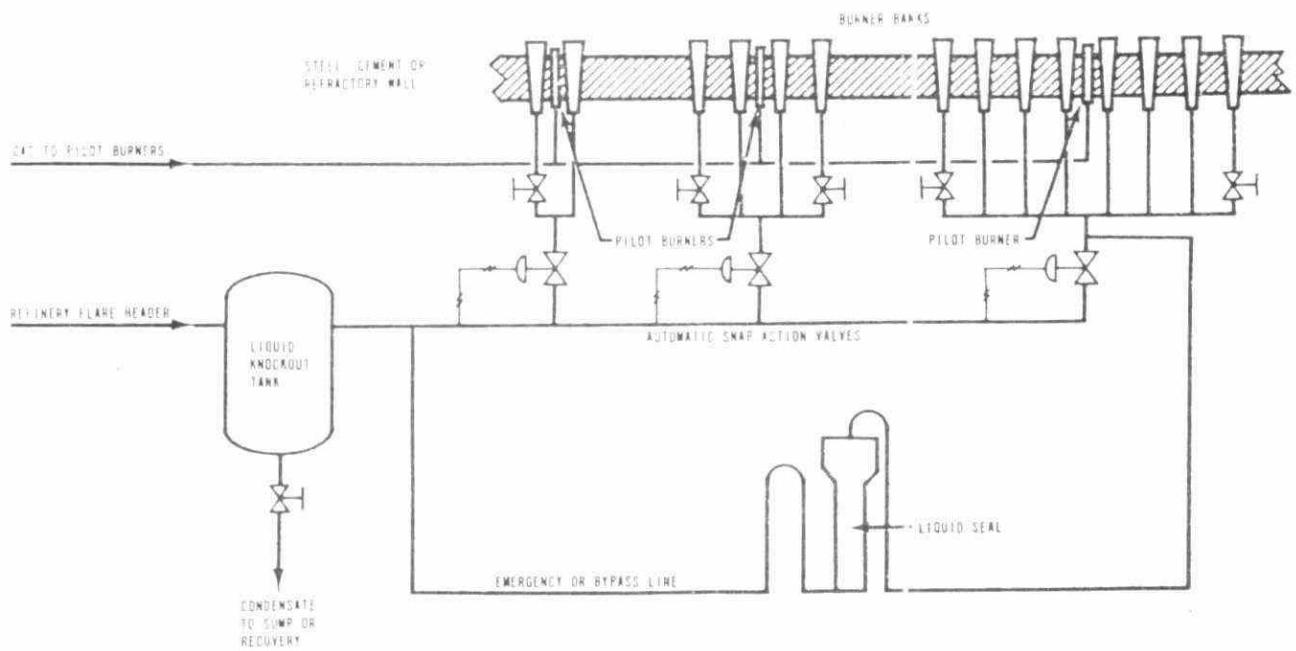
18.19 To prevent unsafe operating pressures in process units during shutdowns and startups and to handle miscellaneous hydrocarbon leaks, the refinery must provide a means of venting hydrocarbon vapours safely. Either a properly sized elevated flare using steam injection or a series of venturi burners actuated by pressure increases is satisfactory. Good instrumentation and properly balanced steam-to-hydrocarbon ratios are prime factors in the design of a safe, smokeless flare. Typical flare types are illustrated in Figures 18-3, 18-4, and 18-5.

Pressure Relief Valves

18.20 In refinery operations, process vessels are protected from overpressure by relief valves. These pressure-relieving devices are normally spring-loaded valves. Corrosion or improper reseating of the valve

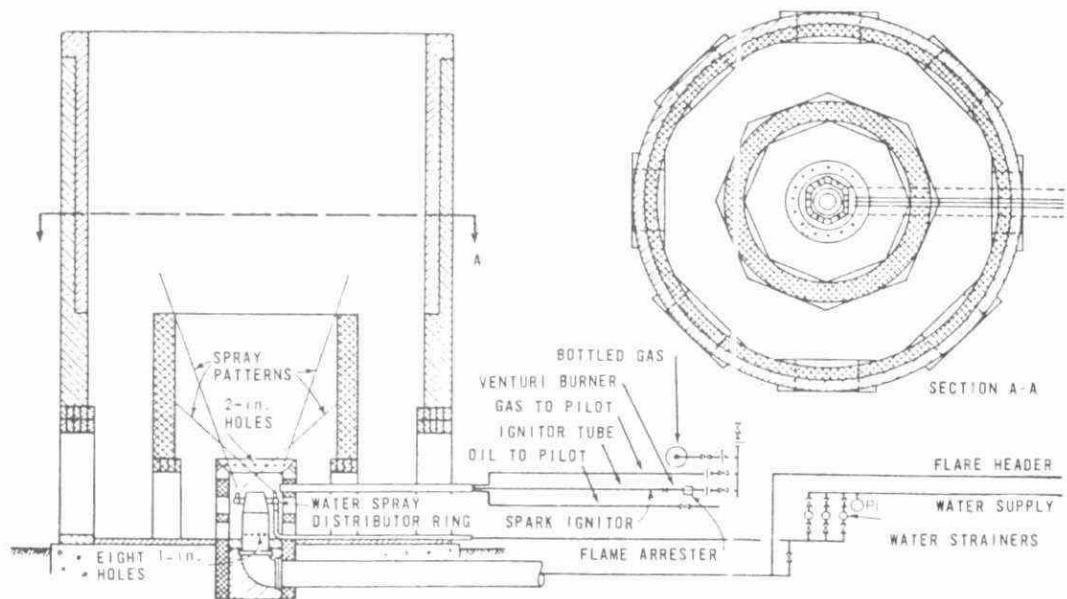


Waste-gas flare system using multistream-jet burner (Cleveland, 1952).



Typical venturi ground flare. The ignitors for pilot burners and the warning element for pilot operation are not shown (American Petroleum Institute, 1957).

FIG. 18-4



Typical water-spray-type ground flare. Six water sprays are shown. Two pilots and two ignitors are recommended (American Petroleum Institute, 1957).

FIG. 18-5

seat results in leakage. Proper maintenance through routine inspections, or use of rupture discs, or manifolding the discharge side to vapour recovery or to a flare minimizes air contamination from this source.

Storage Vessels

18.21 Tanks used to store crude oil and volatile petroleum distillates are a large potential source of hydrocarbon emissions. Hydrocarbons can be discharged to the atmosphere from a storage tank as a result of diurnal temperature changes, filling operations, and volatilization. Control efficiencies of 85 to 100 per cent can be realized by using properly designed vapour recovery (Figure 18-6) or disposal systems, floating-roof tanks (Figure 18-7), or pressure tanks.

Bulk Loading Facilities

18.22 The filling of vessels used for transport of petroleum products is potentially a large source of hydrocarbon emissions. As the product is loaded, it displaces gases containing hydrocarbons to the atmosphere. An adequate method of preventing these emissions consists of collecting the vapours by enclosing the filling hatch and piping the captured vapours to recovery or disposal equipment. Submerged filling and bottom loading also reduce the amount of displaced hydrocarbon vapours.

Catalyst Regeneration

18.23 Modern refining processes include many operations using a solid-type catalyst. These catalysts



Figure 18-6. View of small-capacity vaporsaver gasoline absorption unit (American Airlines, Los Angeles, Calif.).

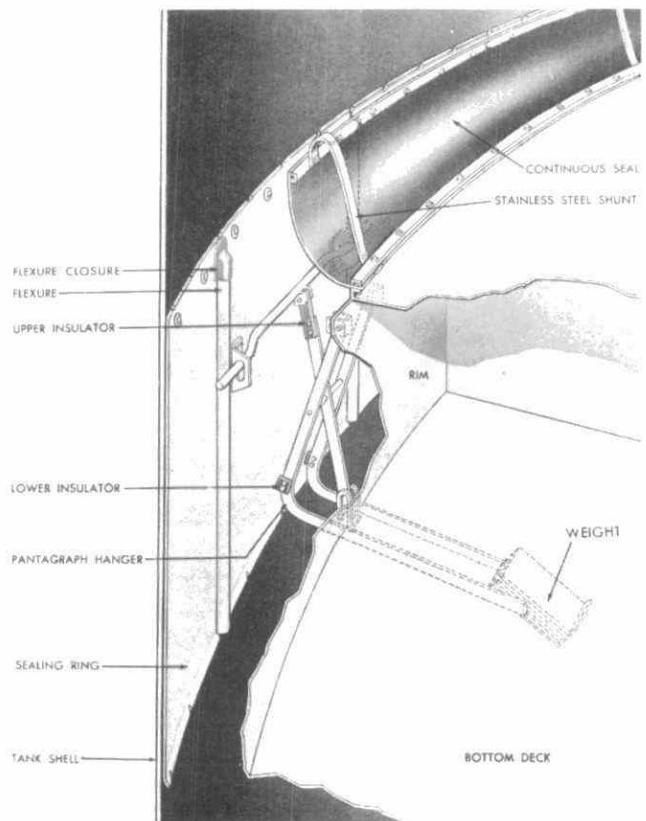


Figure 18-7 Sectional view of double-deck floating-roof's sealing mechanism (Chicago Bridge and Iron Co., Chicago, Ill.).

become contaminated with coke build-up during operation and must be regenerated or discarded. For certain processes to be economically feasible, for example catalytic cracking, regeneration of the catalyst is a necessity and is achieved by burning off the coke under controlled combustion conditions. The resulting flue gases may contain catalytic dust, hydrocarbons, and other impurities originating in the charging stack, as well as the products of combustion.

The dust problem encountered in regeneration of moving-bed type catalysts requires control by water scrubbers and cyclones, cyclones and precipitators, or high-efficiency cyclones, depending upon the type of catalyst, the process, and the regeneration conditions. Hydrocarbons, carbon monoxide, ammonia, and organic acids can be controlled effectively by incineration in carbon monoxide waste-heat boilers. The waste-heat boiler offers a secondary control feature for plumes emitted from fluid catalytic cracking units. This type of visible plume, whose degree of opacity is dependent upon atmospheric humidity, can be eliminated by using the carbon monoxide waste-heat boiler.

Other processes in refining operations employ liquid or solid catalysts. Regenerating some of these catalysts at the unit is feasible. Other catalysts are consumed or require special treatment by their manufacturer. Where regeneration is possible, a closed system can be effected to minimize the release of any air contaminants by venting the regenerator effluent to the firebox of a heater.

Effluent-Waste Disposal

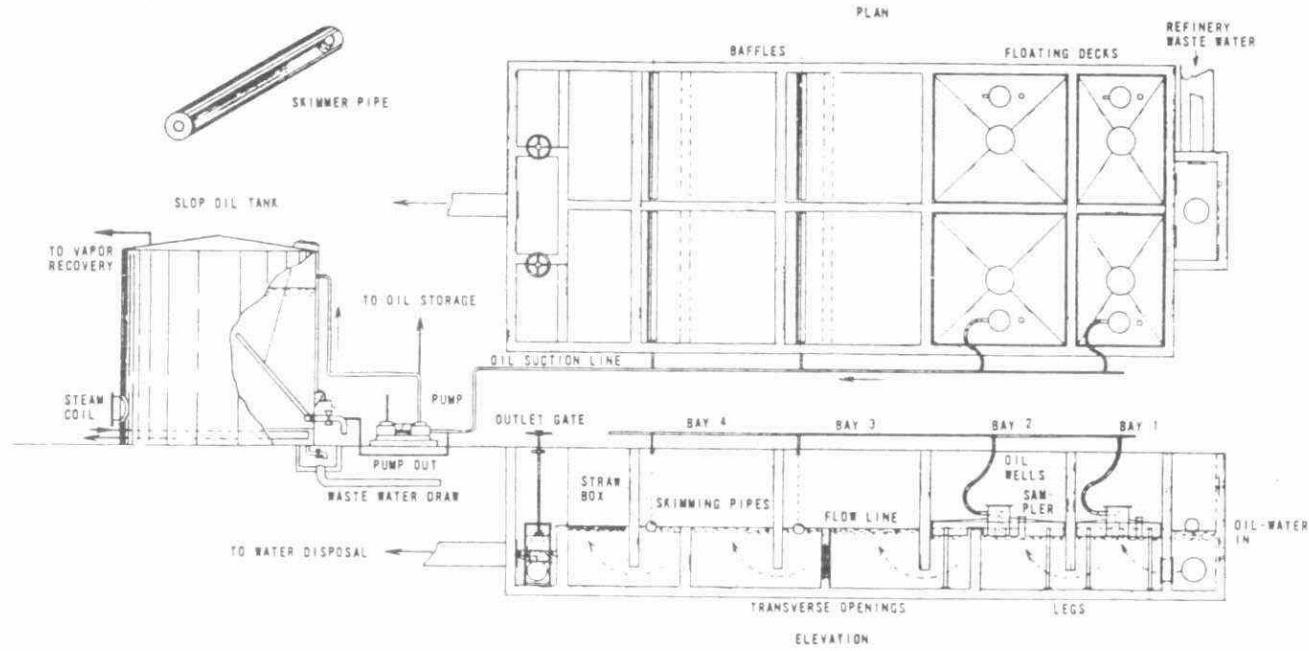
18.24 Wastewater, spent acids, spent caustic and other waste liquid materials are generated by refining operations and present disposal problems. The wastewater is processed through gravity oil-water separators (Figure 18-8). Unless adequate control measures are taken, hydrocarbons contained in the wastewater are emitted to the atmosphere. Acceptable control is achieved by enclosing the separator with a floating roof or a vapour-tight cover. In the latter case, the vapour section should be gas blanketed to prevent explosive mixtures and fires. Vapours should be vented to vapour recovery. Spent waste materials can be recovered as acids or phenolic compounds, or hauled to an acceptable disposal site (ocean or desert).

18.25 The effluent water from the oil-water separator may require further treatment before final discharge. Methods of final effluent clarification include:

1. Filtration
2. Chemical flocculation
3. Biological treatment

18.26 Several different types of filters (e.g. sand filter) may be used, the choice depending upon the properties of the effluent stream and economic considerations.

18.27 Chemical flocculation may be carried out by sedimentation or flotation. In sedimentation process, chemicals such as copper sulphate, activated silica,



A modern oil-water separator.

FIG. 18-8

alum, and lime are added to the wastewater stream before it is fed to the clarifiers. The chemicals cause the suspended particles to agglomerate and settle out as a sediment, which is removed by mechanical scrapers from the bottom. In the flotation process a colloidal floc and air under pressure are injected into the wastewater. The stream is then fed to a clarifier through a back pressure valve that reduces the pressure to atmospheric. The dissolved air is suddenly released as tiny bubbles that carry the particles of oil and coalesced solids to the surface when they are skimmed off by mechanical scrapers.

18.28 Biological treatment units such as trickling filters, activated sludge basins, and stabilization basins are capable of reducing oil, biological oxygen demand (BOD), and phenolic content from effluent water streams. To prevent the release of air pollutants to the atmosphere, certain pieces of equipment, such as clarifiers, digesters, and filters, used in biological treatment, should be covered and vented to recovery facilities or incinerated.

Pumps and Compressors

18.29 Pumps and compressors required to move liquids and gases in the refinery can leak product at the point of contact between the moving shaft and stationary casing. Properly maintained packing glands or mechanical seals minimize the emissions from pumps. Compressor glands can be vented to a vapour recovery system or smokeless flare.

18.30 The internal combustion engines normally used to drive the compressors are fueled by natural or refinery process gas. Even with relatively high combustion efficiency and steady load conditions, some fuel can pass through the engine unburned. Nitrogen oxides, aldehydes, and sulphur oxides can also be found in the exhaust gases. Control methods for reducing these contaminants are being studied.

Air-Blowing Operations

18.31 Venting the air used for "brightening" and agitation of petroleum products of oxidation of asphalt results in a discharge of entrained hydrocarbon vapours and mists, and malodourous compounds. Mechanical agitators that replace air agitation can reduce the volumes of these emission. For the effluent fumes from asphalt oxidation, incineration gives effective control of hydrocarbons and malodours.

Pipeline Valves and Flanges, Blind Changing, Process Drains

18.32 Liquid and vapour leaks can develop at valve stems as a result of heat, pressure friction, corrosion, and vibration. Regular equipment inspections followed by adequate maintenance can keep losses at a minimum. Leaks at flange connections are negligible if the connections are properly installed and maintained. Installation or removal of pipeline blinds can result in spillage of some product. A certain amount of this spilled product evapourates regardless of drainage and flushing facilities. Special pipeline blinds have, however, been developed to reduce the amount of spillage.

18.33 In refinery operation, condensate water and flushing water must be drained from process equipment. These drains also remove liquid leakage or spills and water used to cool pump glands. Modern refining designs provide wastewater-effluent systems with running-liquid-sealed traps and liquid-sealed and covered junction boxes. These seals keep the amount of liquid hydrocarbons exposed to the air at a minimum and thereby reduce hydrocarbon losses.

Cooling Towers

18.34 The large amounts of water used for cooling are conserved by recooling the water in wooden towers. Cooling is accomplished by evapourating part of this water. Any hydrocarbons that might be entrained or dissolved in the water as a result of leaking heat exchange equipment are readily discharged to the atmosphere. Proper design and maintenance of heat exchange equipment minimizes this loss. Advancement of the fin-fan cooling equipment has also replaced the need of the conventional cooling tower in many instances. Process water that has come into contact with a hydrocarbon stream or has otherwise been contaminated with odourous material should not be piped to a cooling tower.

Vacuum Jets and Barometric Condensers

18.35 Some process equipment is operated at less than atmospheric pressure. Steam-driven vacuum jets and barometric condensers are used to obtain the desired vacuum. The lighter hydrocarbons that are not condensed are discharged to the atmosphere unless

controlled. These hydrocarbons can be completely controlled by incinerating the discharge. The barometric hot well can also be enclosed and vented to a vapour disposal system. The water of the hot well should not be turned to a cooling tower.

Effective Air Pollution Control Measures

18.36 Control of air contaminants can be accomplished by process change, installation of control equipment, improved house-keeping, and better equipment maintenance. Some combination of these often proves the most effective solution. Table 18-1 indicates various methods of controlling most air pollution sources encountered in the oil refinery. These techniques are also applicable to petrochemical operations. Most of these controls result in some form of economic savings. Table 18-2 indicates the emissions that can be expected from petroleum refineries.

TABLE 18-1

Suggested Control Measures for Reduction of Air Contaminants
from Petroleum Refining

<u>Source</u>	<u>Control Method</u>
Storage vessels	Vapour recovery systems; floating-roof tanks; pressure tanks; vapour balance; painting tanks white.
Catalyst regenerators	Cyclones - precipitator - CO boiler; cyclones - water scrubber; multiple cyclones.
Accumulator Vents	Vapour recovery; vapour incineration.
Blowdown Systems	Smokeless flares - gas recovery.
Pumps and Compressors	Mechanical seals; vapour recovery; sealing glands by oil pressure; maintenance.
Vacuum jets.	Vapour incineration.
Equipment valves.	Inspection and maintenance.
Pressure relief valves	Vapour recovery; vapour incineration; rupture discs; inspection and maintenance.
Effluent - waste disposal	Enclosing separators; covering sewer boxes and using liquid seal; liquid seals on drains
Bulk-loading facilities.	Vapour collection with recovery or incineration; submerged or bottom loading.
Acid treating	Continuous-type agitators with mechanical mixing; replace with catalytic hydrogenation units; incinerate all vented cases; stop sludge burning.
Acid sludge storage and shipping	Caustic scrubbing; incineration; vapour return system; disposal at sea.
Spent-caustic handling.	Incineration; scrubbing.
Doctor treating	Steam strip spent doctor solution to hydrocarbon recovery before air regeneration; replace treating unit with other, less objectionable units.
Sour-water treating.	Use sour-water oxidizers and gas incineration; conversion to ammonium sulphate.
Mercaptan disposal	Conversion to disulphides; adding to catalytic cracking charge stock; incineration; using material in organic synthesis.
Asphalt blowing	Incineration; water scrubbing (nonrecirculating type).
Shutdowns, turnarounds	Depressurize and purge to vapour recovery.

Table 18-2 EMISSION FACTORS FOR PETROLEUM REFINERIES
EMISSION FACTOR RATING: A

Type of process	Particulates	Sulfur oxides (SO ₂)	Carbon monoxide	Hydrocarbons	Nitrogen oxides (NO ₂)	Aldehydes	Ammonia
Boilers and process heaters ^a							
lb/10 ³ bbl oil burned	840	6,720S ^b	Neg ^c	140	2,900	25	Neg
kg/10 ³ liters oil burned	2.4	19.2S	Neg	0.4	8.3	0.071	Neg
lb/10 ³ ft ³ gas burned	0.02	2s ^d	Neg	0.03	0.23	0.003	Neg
kg/10 ³ m ³ gas burned	0.32	32s	Neg	0.48	3.7	0.048	Neg
Fluid catalytic cracking units ^e							
Uncontrolled							
lb/10 ³ bbl fresh feed	242	493	13,700	220	71.0	19	54
kg/10 ³ liters fresh feed	(93 to 340) ^f	(313 to 525)			(37.1 to 145.0)		
0.695		1,413	39.2	0.630	0.204	0.054	0.155
(0.267 to 0.976)		(0.898 to 1.505)			(0.107 to 0.416)		
Electrostatic precipitator and CO boiler							
lb/10 ³ bbl fresh feed	44.7	493	Neg	220	71.0	19	54
kg/10 ³ liters fresh feed	(12.5 to 61.0)	(313 to 525)			(37.1 to 145.0)		
0.128		1,413	Neg	0.630	0.204	0.054	0.155
(0.036 to 0.175)		(0.898 to 1.505)			(0.107 to 0.416)		
Moving bed catalytic cracking units ^a							
lb/10 ³ bbl fresh feed	17	60	3,800	87	5	12	6
kg/10 ³ liters fresh feed	0.049	0.171		10.8	0.250	0.014	0.034
Fluid coking units ^g							
Uncontrolled							
lb/10 ³ bbl fresh feed	523	NA ^h	Neg	Neg	Neg	Neg	Neg
kg/10 ³ liters fresh feed	1.50	NA	Neg	Neg	Neg	Neg	Neg
Electrostatic precipitator							
lb/10 ³ bbl fresh feed	6.85	NA	Neg	Neg	Neg	Neg	Neg
kg/10 ³ liters fresh feed	0.0196	NA	Neg	Neg	Neg	Neg	Neg

Table 18-2 (continued). EMISSION FACTORS PETROLEUM REFINERIES
EMISSION FACTOR RATING: A

Type of process	Particulates	Sulfur oxides (SO ₂)	Carbon monoxide	Hydro-carbons	Nitrogen oxides (NO ₂)	Aldehydes	Ammonia
Compressor internal combustion engines ^a lb/10 ³ ft ³ gas burned kg/10 ³ m ³ gas burned	Neg Neg	2s 32s	Neg Neg	1.2 19.3	0.9 14.4	0.1 1.61	0.2 3.2
Blowdown systems ^a Uncontrolled lb/10 ³ bbl refinery capacity kg/10 ³ liters refinery capacity	Neg Neg	Neg Neg	Neg Neg	300 0.860	Neg Neg	Neg Neg	Neg Neg
Vapor recovery system or flaring lb/10 ³ bbl refinery capacity kg/10 ³ liters refinery capacity	Neg Neg	Neg Neg	Neg Neg	5 0.014	Neg Neg	Neg Neg	Neg Neg
Process drains, Uncontrolled lb/10 ³ bbl waste water kg/10 ³ liters waste water	Neg Neg	Neg Neg	Neg Neg	210 0.600	Neg Neg	Neg Neg	Neg Neg
Vapor recovery or separator covers lb/10 ³ bbl waste water kg/10 ³ liters waste water	Neg Neg	Neg Neg	Neg Neg	8 0.023	Neg Neg	Neg Neg	Neg Neg
Vacuum jets ^a Uncontrolled lb/10 ³ bbl vacuum distillate kg/10 ³ liters vacuum distillate	Neg Neg	Neg Neg	Neg Neg	130 0.370	Neg Neg	Neg Neg	Neg Neg
Fume burner or waste-heat boiler lb/10 ³ bbl vacuum distillate	Neg	Neg	Neg	Neg	Neg	Neg	Neg

Table 18-2(continued). EMISSION FACTORS FOR PETROLEUM REFINERIES
EMISSION FACTOR RATING: A

Type of process	Particulates	Sulfur oxides (SO ₂)	Carbon monoxide	Hydrocarbons	Nitrogen oxides (NO ₂)	Aldehydes	Ammonia
kg/10 ³ liters vacuum distillate	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Cooling towers ^a							
Ib/10 ⁶ gal cooling water	Neg	Neg	Neg	6	Neg	Neg	Neg
kg/10 ⁶ liters cooling water	Neg	Neg	Neg	0.72	Neg	Neg	Neg
Pipeline valves and flanges ^a							
Ib/10 ³ bbl refining capacity	Neg	Neg	Neg	28	Neg	Neg	Neg
kg/10 ³ liter refining capacity	Neg	Neg	Neg	0.080	Neg	Neg	Neg
Vessel relief valves ^a							
Ib/10 ³ bbl refining capacity	Neg	Neg	Neg	11	Neg	Neg	Neg
kg/10 ³ liter refining capacity	Neg	Neg	Neg	0.031	Neg	Neg	Neg
Pump seals ^a							
Ib/10 ³ bbl refining capacity	Neg	Neg	Neg	17	Neg	Neg	Neg
kg/10 ³ liter refining capacity	Neg	Neg	Neg	0.049	Neg	Neg	Neg
Compressor seals ^a							
Ib/10 ³ bbl refining capacity	Neg	Neg	Neg	5	Neg	Neg	Neg
kg/10 ³ liter refining capacity	Neg	Neg	Neg	0.014	Neg	Neg	Neg
Miscellaneous (air blowing, sampling, etc.) ^a							
Ib/10 ³ bbl refining capacity	Neg	Neg	Neg	10	Neg	Neg	Neg
kg/10 ³ liter refining capacity	Neg	Neg	Neg	0.029	Neg	Neg	Neg

^aReference 1.^bS = Fuel oil sulfur content (weight percent); factors based on 100 percent combustion of sulfur to SO₂ and assumed density of 336 lb/bbl (0.96 kg/liter).^cNegligible emission.^ds = refinery gas sulfur content (lb/100 ft³); factors based on 100 percent combustion of sulfur to SO₂.^eReferences 1 through 6.^fNumbers in parenthesis indicate range or values observed.^gReference 3.

SUBJECT:

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

TOPIC: 19

MISCELLANEOUS INDUSTRIAL
PROCESSES

OBJECTIVES:

The trainee will be able to:

1. Sketch a flow diagram of a typical hot-mix asphalt batch plant; describe the air contaminant emissions expected from a typical hot-mix asphalt batch plant; and list the emission source points;
2. Describe the wet process of Portland cement production; the air contaminant emissions to be expected; and how they are controlled;
3. Describe the lime production process;
4. Detail the air contaminant emission source points of a concrete-batching plant, and describe how they are controlled;
5. Describe the air contaminant emissions from a paint baking oven, their cause, and their major effects;
6. Detail the air contaminant emission source points of a feed and grain mill and describe how they are controlled.

MISCELLANEOUS INDUSTRIAL PROCESSES

HOT-MIX ASPHALT BATCH PLANTS

19.1 Hot-mix asphalt paving consists of a combination of aggregates, uniformly mixed and coated with asphalt cement. An asphalt batch plant is used to heat, mix, and combine the aggregate and asphalt in the proper proportions to give the desired paving mix. After the material is mixed it is transported to the paving site and spread as a loosely compacted layer with a uniformly smooth surface. While still hot, the material is compacted and densified by heavy motor-driven rollers to produce a smooth, well-compacted surface.

19.2 Asphalt paving mixes may be produced from a wide range of aggregate combinations, each having particular characteristics and suited to specific design and construction uses. Aside from the amount and grade of asphalt cement used the principal characteristics of the mix are determined by the relative amount of:

Coarse aggregate	(retained on #8 mesh Sieve),
Fine aggregate	(passing #8 mesh sieve), and
Mineral dust	(passing #200 mesh sieve),

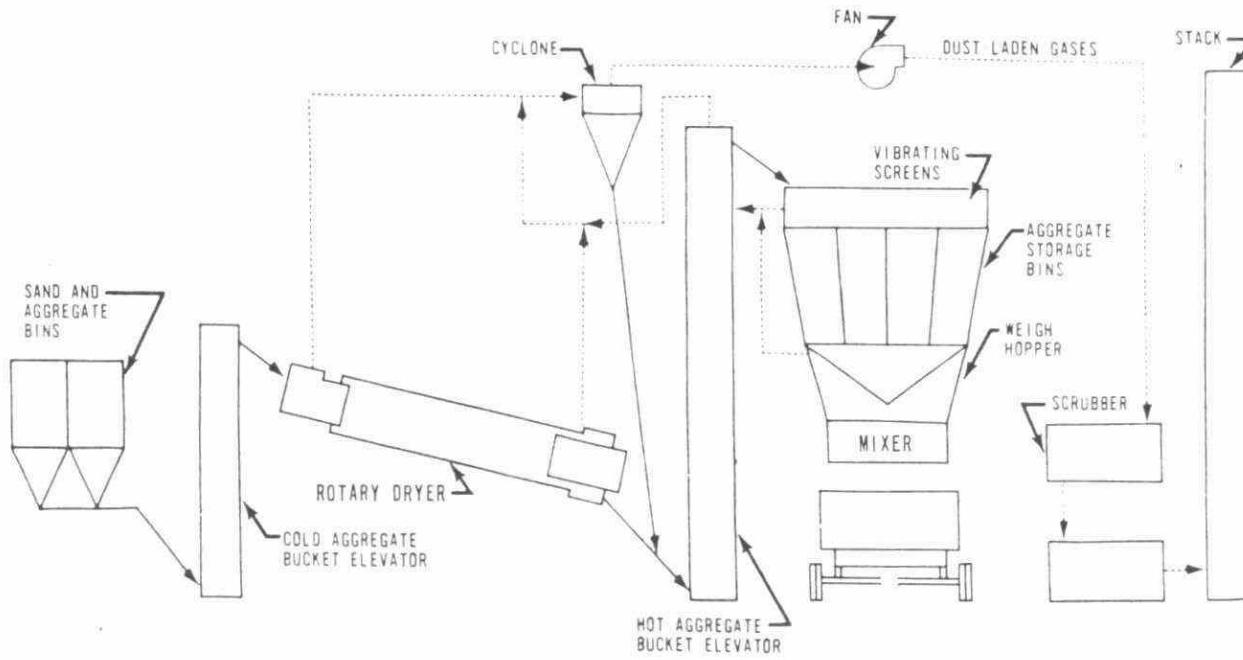
19.3 The aggregate composition may vary from a coarse-textured mix having a predominance of coarse aggregate to a fine-textured mix having a predominance of fine aggregate. Aggregates of all sizes up to $2\frac{1}{2}$ " are used in hot-mix asphalt paving. The coarse aggregates usually consist of crushed stone, crushed slag, crushed gravel, or combinations thereof, or of such material as decomposed granite naturally occurring in a fractured condition, or of a highly

angular natural aggregate with a pitted or rough surface texture. The fine aggregates usually consist of natural sand and may contain added materials such as crushed stone, slag, or gravel. All aggregates must be free from coatings of clay, silt, or other objectionable matter, and should not contain clay particles or other fine materials. Mineral filler or dust is used in some types of paving. It usually consists of finely ground particles of crushed rock, limestone, hydrated lime, Portland cement, or other non-plastic mineral matter. A minimum of 65% of this material must pass a #200 mesh sieve.

19.4 Asphalt cement is used in amounts of 3 to 12% by weight and is made from refined petroleum. It is solid at ambient temperature and is usually used as a liquid at 135° to 165° C.

19.5 A typical hot-mix asphalt batch plant (Figure 19-1) consists of an oil or gas-fired rotary drier, a screening and classifying system, weigh boxes for asphalt cement and aggregate, a mixer, and the necessary conveying equipment consisting of bucket elevators and belt conveyors. Equipment for the storage of sand, gravel, asphalt cement, and fuel oil is provided in most plants. Heaters for the asphalt cement and fuel oil tanks are also used.

19.6 Plants vary in size, and may produce up to 6,000 lb. batches with production rates of from 100 to 250 tons per hour. Aggregate is usually conveyed from the storage bins to a rotary drier by means of a belt conveyor and bucket elevator. The drier is usually either oil or gas-fired and heats



Flow diagram of a typical hot-mix asphalt paving batch plant.

FIGURE 19-1

the aggregate to temperatures ranging from 120° to 175°C. The dried aggregate is conveyed by bucket elevator to the screening equipment where it is classified and dumped into elevated storage bins. Selected amounts of the proper size aggregate are dropped from the storage bins to the weigh hopper. The weighed aggregate is then dropped into the mixer along with the hot asphalt cement. The batch is mixed and dumped into waiting trucks for transportation to the paving site. Mineral filler can be added directly to the weigh hopper by means of an auxiliary bucket elevator and screw conveyor. Fine dust in the combustion gases from the rotary drier is partially recovered in a pre-cleaner and discharged continuously into the hot dried aggregate leaving the drier.

Emissions

19.7 The largest source of dust emission is the rotary drier. Other sources are the hot aggregate bucket elevator, the vibrating screens, the hot aggregate bins, the aggregate weight hopper, and the mixer. Particle size distribution of the drier feed has an appreciable effect on the discharge of dust. Tests show that about 55% of the minus #200 mesh fraction in the drier feed can be lost in processing. The dust emissions from the secondary sources vary with the amount of fine material in the feed and the mechanical condition of the equipment.

CEMENT PRODUCTION

19.8 Portland cement is manufactured by heating a mixture of lime and clay to a temperature in excess of 1,300°C, forming calcium silicates and aluminates

which clinker while cooling. This clinker is then ground to the familiar grey powder.

Wet Process (Figure 19-2)

19.9 The clay used in cement manufacture is passed through a washmill, freed of large particles and impurities and transferred to a storage tank; this prepared clay is known as 'slip'. The slip is then mixed with crushed chalk in a wet grinding mill, the mixture usually comprising three and a half parts chalk to one part clay, by weight. The mixture, known as 'slurry' is passed to an open tank.

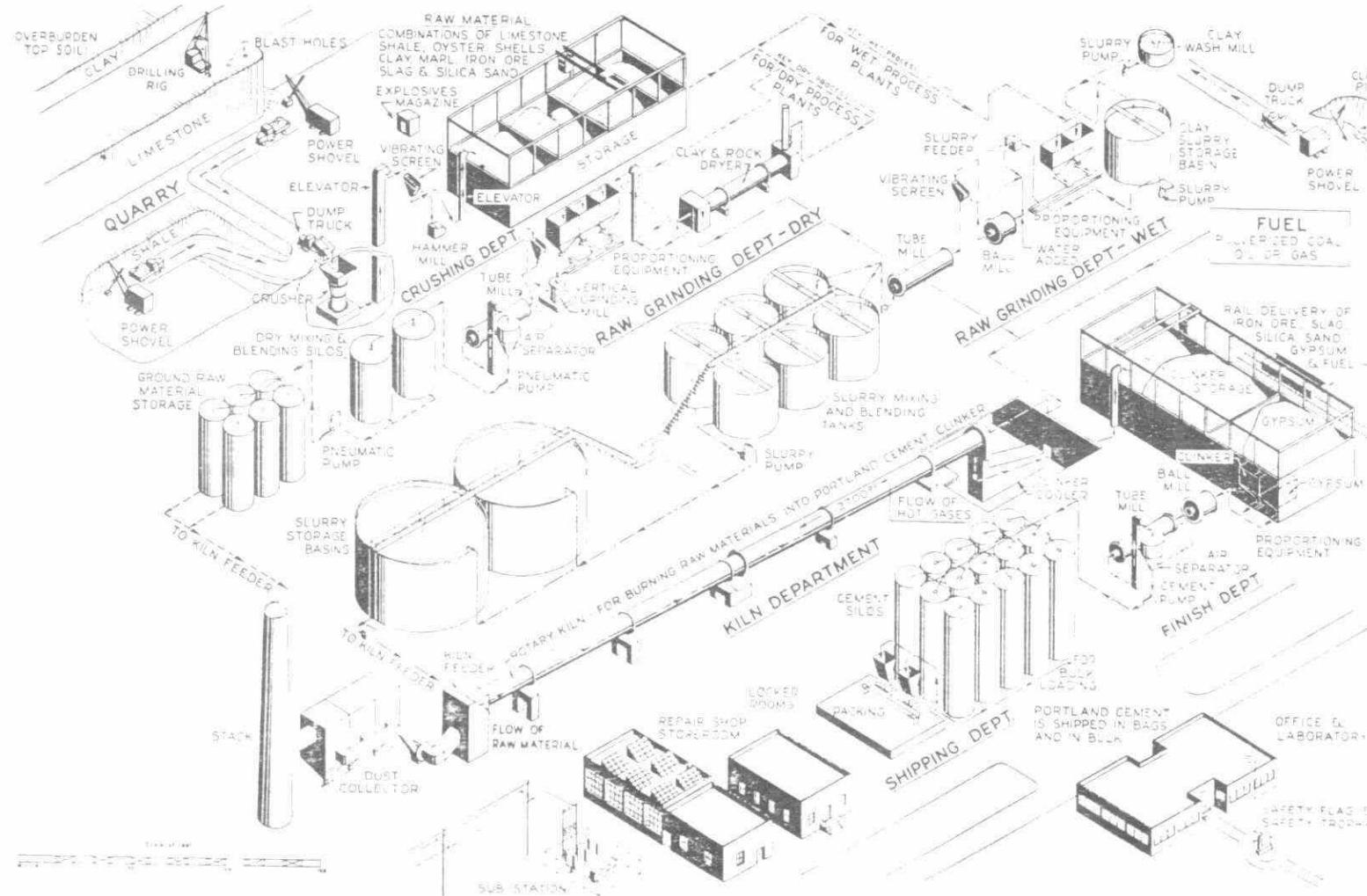
19.10 From the open tank the cement slurry is pumped to a rotary cement kiln. This is a steel cylinder up to 600 ft. in length and 8 to 20 ft. in diameter lined with high-alumina or high-magnesia bricks. The cylinder is slightly inclined to the horizontal so that the contents may gradually descend as the cylinder rotates. Inside the kiln are numerous slack chains which fall across it as it rotates. These chains help to bring as much slurry as possible into contact with the hot flue gases. The slurry enters the upper end of the kiln. Oil, gas or pulverized fuel burners are situated at the lower end, injecting a very hot flame which travels up the kiln.

19.11 Heat is absorbed by the product and the kiln walls, reducing the exit gas temperature. The slurry passes through three zones. In the first zone it is dried, in the second the chalk in the mixture loses its carbon dioxide and becomes quicklime, and in the third or lower zone the oxides of calcium, aluminum and silicon combine to form

FIGURE 19-2

Isometric flowchart for the manufacture of portland cement by both dry and wet processes (Portland Cement Association)

19-6



cement clinker. It takes from 1 to 3 hours for the material to pass through the kiln. The white hot clinker is then discharged into air-quenching coolers, simultaneously pre-heating air for combustion purposes. After this it is pulverized, then finely ground in tube ball mills. During the grinding process any retarders or other necessary agents are added, after which the product is packaged.

19.12 About two-thirds of the fly-ash from pulverized fuel is trapped by the slurry or clinker. The remainder passes with cement dust from the upper end of the kiln and must be dealt with by control equipment. Cyclone dust arresters and electrostatic precipitators are employed, sometimes in combination. One of the difficulties lies in the fact that the waste gases contain about 40 per cent moisture, and unless the temperature of the gases is kept above acid dew point corrosion and electrical failure of the precipitators may occur. This problem is more likely to occur where flues are long, and every effort is made to avoid this in new plants. With control equipment in good order, collecting efficiencies of 97 per cent or more may be achieved.

19.13 For final disposal chimneys of 200 - 250 ft. are usually sufficient, although heights up to 400 ft. have been required in some instances. For the production of each ton of cement, some 200,000 cu. ft. of waste gases are discharged to atmosphere. Conversion to oil-firing solves the problem of fly-ash, but does not solve the problem of cement dust which becomes entrained in the effluent gases. Despite improvements in dust-arresting efficiencies, grey dust deposits are still a characteristic of cement manufacturing districts.

19.14 Cement dust problems may also arise from the grinding, conveying, packaging, etc., processes. Bag filtration and electrical filtration have been applied successfully to these problems. Bulk loading also gives rise to dust emission hazards and requires similar treatment.

Dry Process (Figure 19-2)

19.15 The dry process is displacing the wet slurry process, because of heat saving and the more accurate control and mixing of the raw materials it makes possible. The materials are crushed, milled, dried, sized, proportioned, then finely ground in tube mills. After thorough mixing and blending the dry powder is fed directly to the heated rotary kiln where the chemical reactions take place.

LIME PRODUCTION

19.16 Calcium oxide or quicklime is made by heating limestone, i.e. calcium carbonate, to temperatures of $1,200^{\circ}$ to $1,300^{\circ}\text{C}$. The chemical reaction which takes place is:



19.17 The carbon dioxide is driven off to atmosphere, this being the only change. The process is known as 'calcination'. Earlier kilns, now obsolete, were tunnel and vertical shaft kilns with outside heating hearths. The most modern forms of continuous kiln are the vertical steel kiln lined with firebrick or the rotary horizontal kiln.

Limestone is crushed and loaded continuously into the top of the vertical kiln (Figure 19-3) the lime being withdrawn from a hopper at the base.

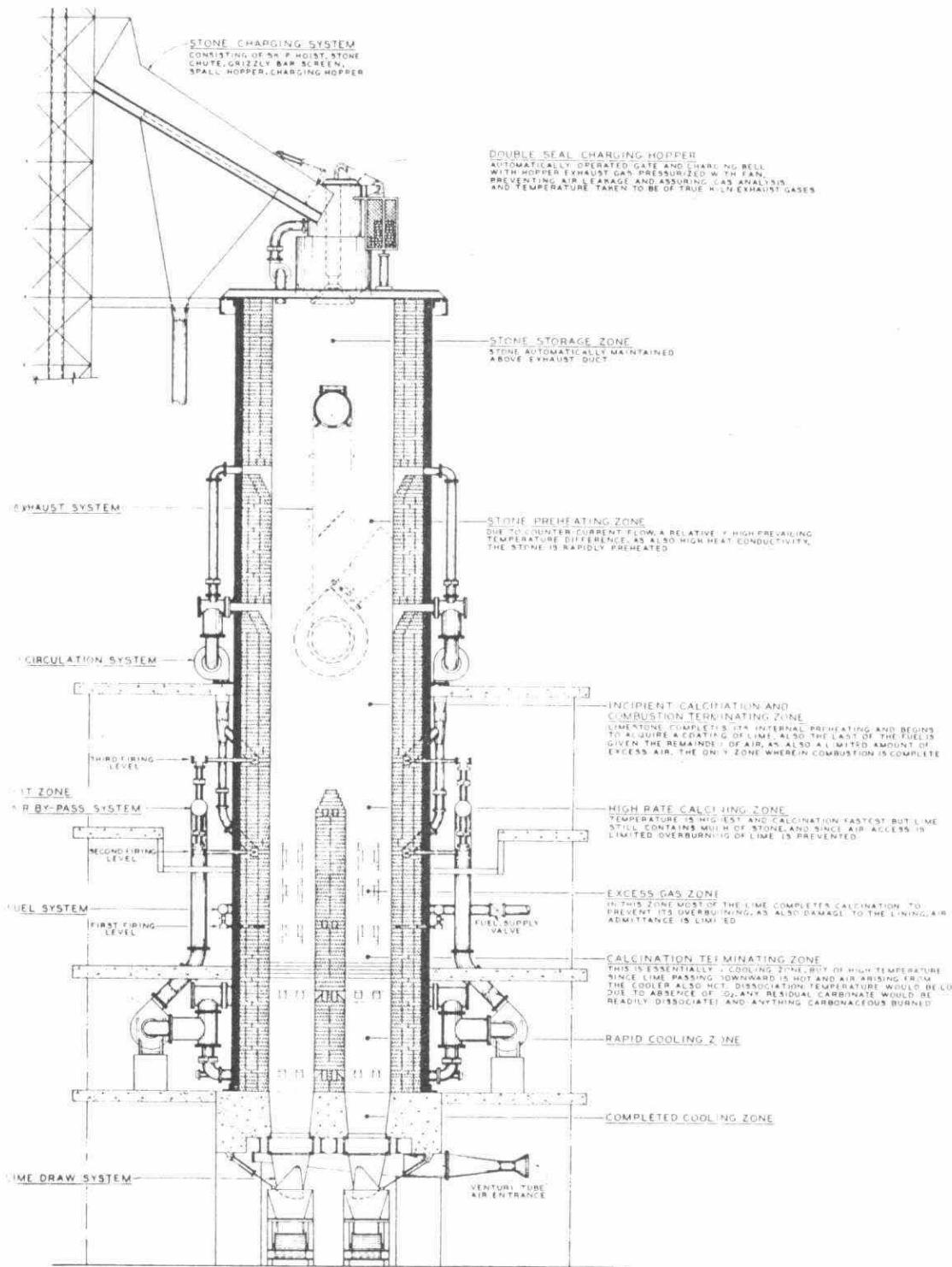


FIGURE 19-3

Natural gas-fired vertical lime kiln
(Azbe Corp., Clayton, Mo.)

Each lump of limestone is in the kiln about 6 hours gradually falling towards the hot zone. Heat is supplied from the combustion of coal, oil or producer gas. These fuels are fired externally, the flames and hot gases passing through the mass of limestone in the kiln. Kilns of this type are costly to build but economical to run; a high degree of control can be exercised over the process and the lime is produced free from contamination.

19.18 Coal-fired kilns give rise to complaints of dark smoke emission. This problem arises because of the difficulties of completing the combustion process in an atmosphere consisting largely of nitrogen and carbon dioxide. Smoke may be reduced by introducing air mechanically into the firing zone of the kiln, or washing the smoke in a venturi type scrubber. A kiln may also be converted to oil-firing or producer-gas firing, but in each case the problem is one of maintaining lime quality. Oil may also give rise to smoke emission if not fully burned externally to the kiln.

19.19 Lime is manufactured in rotary kilns in a similar manner to that used for cement manufacture. They operate on fine or small lumps of limestone, or a moist calcium carbonate sludge or slurry.

CONCRETE-BATCHING PLANTS

19.20 Concrete-batching plants store, convey, measure, and discharge the ingredients for making concrete to mixing or transportation equipment. One type is used to charge sand, aggregate, cement, and water to transit-mix trucks, which mix the batch en route to the site where the concrete is to be poured; this operation is known as "wet batching". Another type is used to charge the sand, aggregate, and cement to flat bed trucks, which transport the batch to paving machines where water is added and mixing takes place; this operation is known as "dry batching". A third type employs the use of a central mix plant, from which wet concrete is delivered to the pouring site by dump truck or portable containers.

19.21 In a typical wet concrete batching plant, sand and aggregates are elevated by belt conveyor or clam shell crane or bucket elevator to overhead storage bins. Cement from bottom-discharge hopper trucks is conveyed to an elevated storage silo. Sand and aggregates for a batch are weighed by successive additions from the overhead bins to a weigh hopper. Cement is delivered by a screw conveyor from the silo to a separate weigh hopper. The weighed aggregate and cement are dropped into a gathering hopper and flow into the receiving hopper to the transit-mix truck. At the same time, the required amount of water is injected into the flowing stream of solids.

19.22 Dry concrete batching plants pose a much more difficult dust control problem than wet batching plants. Since most plants that do dry batching also do wet batching, the gathering hopper must be set high enough to accommodate transit-mix trucks.

Since the receiving hopper of most transit-mix trucks is several feet higher than the top of the flat-bed trucks used in dry batching, there is a long free fall of material when dry batch is dropped. This produces a considerable amount of dust.

19.23 In a central mix plant concrete is mixed in a stationary mixer, discharged into a dump truck or portable container, and transported in a wet mixed condition to the pouring site. From an air pollution control standpoint, this type of operation is preferable to dry batching. The dust is more easily captured at the batch plant, and further, there is no generation of dust at the pouring site. The operation is also preferable to wet batching because designing control equipment for a stationary mixer is easier than it is for a transit-mix truck-loading area.

Emissions

19.24 Dust results from the material used, and cement dust can be emitted from several points; the receiving hopper, the elevator, and the silo. Other points of possible dust emissions are the cement weigh hopper, the gathering hopper, and the mixer. A hood installation for a truck-loading station is illustrated in Figure 19-4.

19.25 A typical cement-receiving and storage system is shown in Figure 19-4. The receiving hopper is at or below ground level. If designed to fit the canvas discharge tube of the hopper truck, little or no dust is emitted at this point. The cement silo must be vented to allow displaced

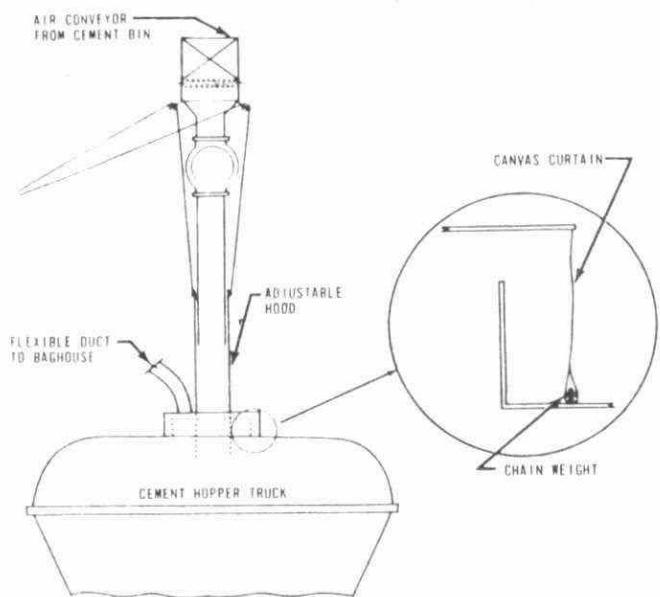


FIGURE 19-4

Hood for truck-loading station.

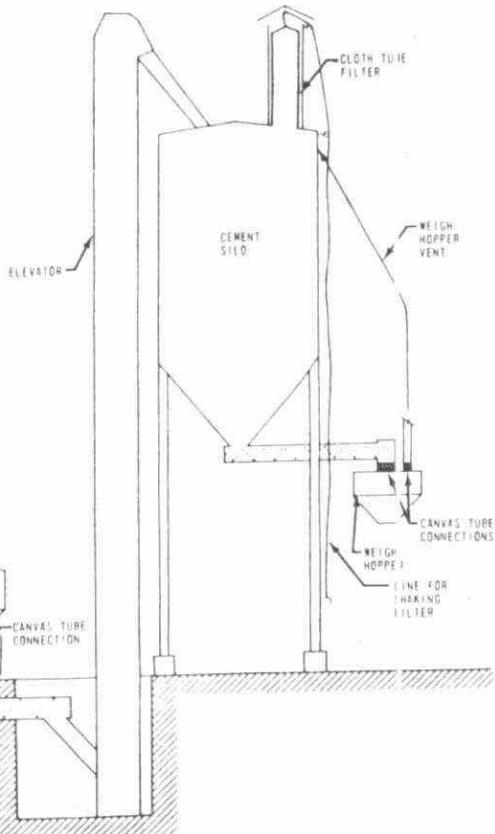


FIGURE 19-5

Cement-receiving and storage system.

air to escape. Unless this vent is filtered a significant amount of dust escapes. The filter in the illustration consists of a cloth tube with a stack and weather cap for protection. The pulley arrangement allows it to be shaken from the ground. Where a baghouse is used to control other larger cement dust sources, the silo can easily be vented to the same baghouse.

PAINT-BAKING OVENS

19.26 Although bake ovens have extensive industrial applications this section is limited to those used to dry or harden surface coating concurrently with the removal of organic solvents by evaporation. Moreover, the word paint is used throughout as a general term for any of the many and varied types of surface coatings, for example, inks, varnishes, paints, enamels, lacquers, shellacs, and resins.

19.27 Paint baking causes not only the evaporation of the organic solvents used as diluents and thinners but also the drying and hardening of a surface coating. The essential requirement in paint baking is that the paint be exposed to the proper degree and amount of heat, but there are other requirements, as follows:

- 1) Within the oven, the atmosphere resulting from the vaporization of organic solvents from the paint must be maintained below the lower explosive limit;
- 2) When the doors are open and employees are loading or unloading the oven, the atmosphere within the oven must be kept well below the toxic level;

- 3) The atmosphere in which the painted surface is baked must, in some cases but not all, be kept free from the products of incomplete combustion of the oil or gas used for firing;
- 4) The atmosphere within the oven must be free from dust; and
- 5) Air pollution potentials of emissions from the ovens to the outside atmosphere must be evaluated.

19.28 A bake oven is a heated enclosure used industrially to dry and bake materials at elevated temperatures. In paint drying and baking, these temperatures may range from 38° to 315°C . The typical construction of a bake oven consists of a framework of heavy structural steel that supports an inner and outer shell of heavy-gauge steel sheet metal. The space between the inner and outer shell is filled with insulation. In some ovens, the products of combustion enter and come into direct contact with the work in process; in other ovens, the heating is indirect, and the products of combustion do not enter the oven nor do they at any time come into contact with the work in process. The source of heat may be gas, electricity, oil, steam, or infra-red lamps, whichever is available and appropriate to the process. In all bake ovens, accurate, dependable temperatures control and uniform heating are requisites. All three methods of heat transfer are used in any bake oven.

19.29 An exhaust fan should be provided for all but the smaller ovens. The exhaust duct's intake openings should be located in the area of the greatest concentration of vapours. In general, the organic vapours from volatile organic solvents customarily used in paints are heavier than air. For this reason, bottom ventilation of a paint-baking oven is indicated. The products of combustion from the burning of fuel are, however, lighter than air and should, therefore, be vented from the top. The products of combustion from indirectly gas or oil-fired air heaters are preferably exhausted by a separate draught fan not connected to the oven's ventilation.

19.30 Batch process paint-baking ovens have an insulated chamber, some form of air circulation, a combustion system, a heat exchanger, a variety of safety controls, fresh air filters, and either a natural-draught or an induced-draught exhaust system. The painted products to be baked may rest on permanent racks or hooks inside the oven or may be placed on trucks that can be moved in and out of the oven for loading or unloading. Batch paint-baking ovens offer the advantage of low investment and are completely adequate for many jobs. Because the items to be baked are all put into the oven at one time, the organic solvents do not evaporate at a constant rate. Since a peak evaporation rate is reached within a few minutes after loading, all the organic solvents will have evaporated long before the work load is removed from the oven.

19.31 For large volume production, continuous type paint-baking ovens are usually used. These are high production machines that permit a precise control of baking conditions. They can be designed and built

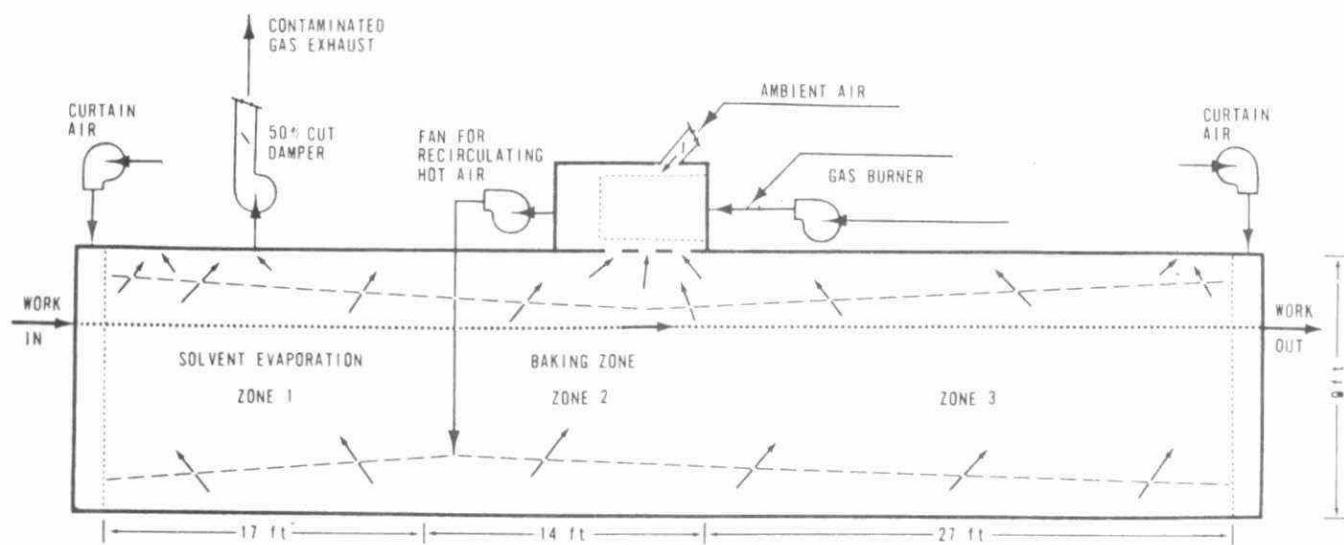
in units to meet any production requirements. A continuous bake oven (Figure 19-6) consists principally of an insulated cabinet with positively controlled circulation of heated air, combustion systems, safety controls, fresh air filters, induced draught exhaust, and a moving conveyor or belt by which the painted product is carried into, through and out of the oven. Automatic control devices maintain any desired baking conditions. Because the work load is introduced into a continuous oven in a steady stream by means of an endless belt or conveyor the evaporation of organic solvents approaches a constant rate.

Emissions

19.32 The air contaminants emitted from paint baking ovens are as follows:

- 1) Smoke and products of incomplete combustion arise from the improper operation of a gas or oil-fired combustion system used for heating the oven;
- 2) Organic solvent vapours arise from the evaporation of the thinners used in the surface coatings. The composition of the organic solvent vapours emitted from a paint baking oven might be expected to have the same composition as that of the organic solvents used in the formulation and thinning of the surface coating, but they do not. Partially oxidized and polymerized compounds are produced at bake oven temperatures. When effluent from paint baking ovens is irradiated in the presence of nitric oxide (NO), it can produce eye irritation as severe as that produced by automobile exhaust;

- 3) The aerosols resulting from the partial oxidation and polymerization of the organic solvents and resins used in the paint formulation create odour problems. Moreover, these emissions are extremely irritating to eyes even without irradiation.



A direct-heated gas-fired recirculating continuous paint baking oven.

FIGURE 19-6

FEED AND GRAIN MILLS

19.33 Changes in feeding have resulted in animals being increasingly moved from cattle range and rural farm forage areas to confined pens and feed lots near urban areas. This transition tends to locate the feed and grain plants in congested areas where air pollution problems arise. The handling and manufacture of feed and grain products generates many varieties and concentrations of dust. These dusts are the sole air contaminants from these plants.

19.34 To pinpoint the sources of dust, a simplified diagram of feed mill flow is presented in Figure 19-7. The drawing delineates basic equipment in solid lines and dust control equipment in dotted lines. Solid-line arrows indicate the flow of basic material from process to process. Dotted-line arrows indicate the forced discharge of dusty air to collectors.

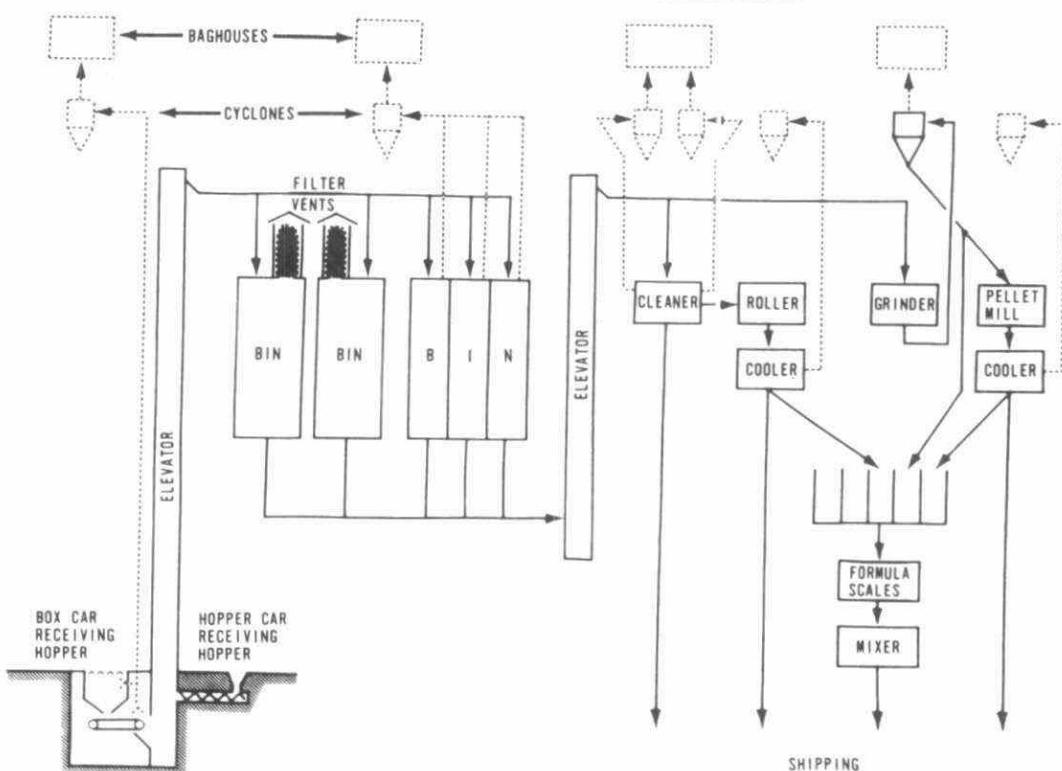


Figure 19-7 Flow diagram of a simplified feed mill. Basic equipment shown in solid lines, dust control equipment, in dotted lines.

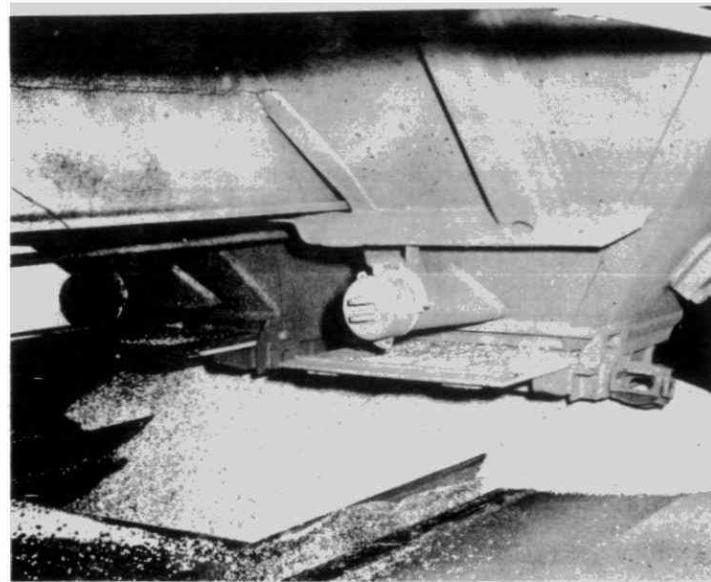
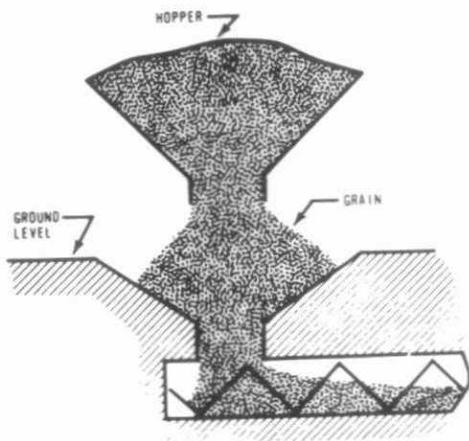


Figure 19-8 Hopper bottom railroad car unloading grain into a shallow hopper by the choked-feed method (Koppel Bulk Terminal, Long Beach, Calif.).

19.35 Feed materials are shipped to feed and grain plants in railroad cars and trucks. These carriers may be classified according to the type of unloading operation used.

19.36 One class includes hopper bottom railroad cars, trucks and trailers, trucks with self-contained conveyors, and hoist dump vehicles. The flow of materials from these self-unloading shipping containers may be regulated so as to fill an inclined chute or shallow hopper as rapidly as the material is removed. This is the choked-feed method of unloading, in which a solid stream of material moves slowly into the receiving system with little or no dust emissions. Figure 19-8 illustrates choked-feed receiving from a hopper bottom railroad car. Canvas boots or socks may be fastened to the spouts and extend down within inches of the hopper gratings.

19.37 Another class includes flat bed trucks and box cars capable of being emptied into receiving hoppers only by mechanical plows or shovels. The carrier beds are about 3 feet above the hopper gratings, which are located at track or ground level. The flat bed carriers are usually unloaded into deep, large-capacity receiving hoppers. The excess surge-holding capacity allows enough time between car unloadings for an empty car to be replaced by a full car, while the handling system continues to convey material out of the hopper. This method provides for receiving the maximum number of cars or trucks per day and may also effect some savings in labor costs.

19.38 Feed materials are also unloaded from carriers by pneumatic conveyors, (Figures 19-9 and 10). The material may be fed manually to a flexible suction tube, connected

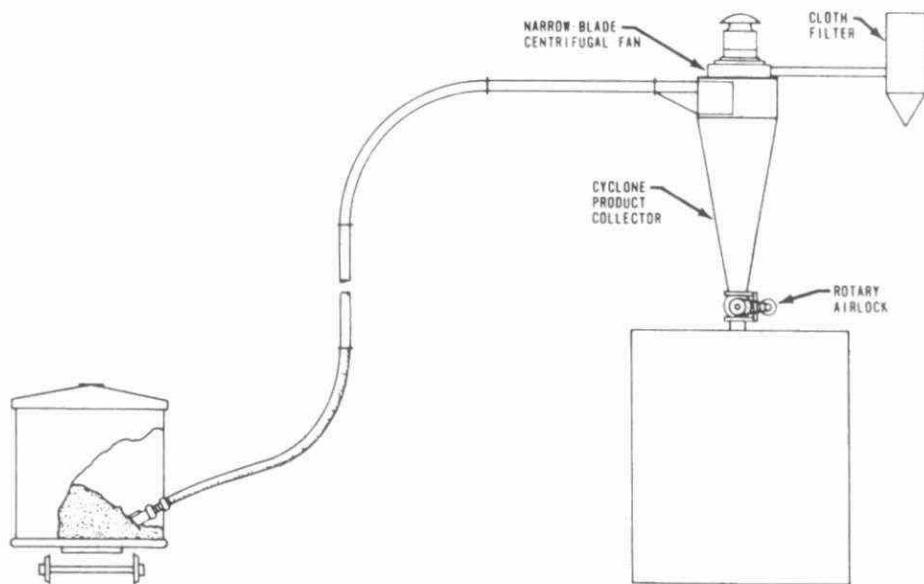


Figure 19-9 Negative-pressure conveying system.

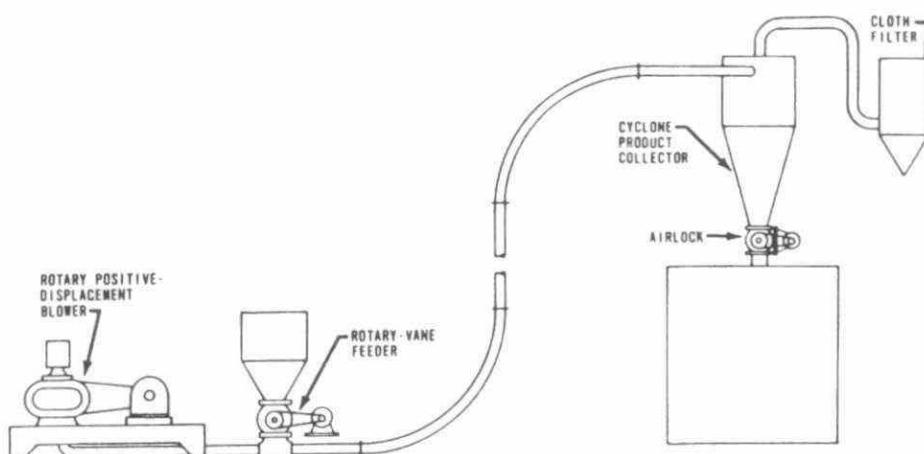


Figure 19-10 Positive-pressure conveying system.

to a pullthrough cyclone, which separates the feed materials from the air conveying system and drops them into a storage bin. Another pneumatic unloading system type uses specially constructed hopper bottom cars or trucks equipped with air or mechanical agitation devices. These devices feed the material through a rotary valve to a pressure-type pneumatic conveyor. The airborne material from this type of conveyor is also separated by a cyclone and dropped into storage.

19.39 Grain and feed storage bins may be single or multiple compartmented. They are usually constructed of steel or concrete. Each bin or compartment is enclosed by a dust-tight cover incorporating an adequately sized vent. This vent provides an escape for displaced air during filling and prevents the bin from buckling under external atmospheric pressure during the discharge operation.

19.40 From the storage bins, whole grains are conveyed to cleaning, rolling, grinding, and other plant processes. The processed grains may be shipped to consumers or held for feed formulation. Finished feed formulas are compounded from vitamins, antibiotics, minerals, and all the processed materials. These compounds may be prepared in the form of finely ground mash, pellets, or mixed mash and pellets. The feeds may be shipped from the mill in plant-owned delivery trucks, common carrier trucks, or by rail.

19.41 Cleaning includes the several mechanical processes by which dockage is removed from grain. Dockage is made up of dust, sticks, stones, stalks, stems, weed seeds, and other grains. A portion, if not the majority of this undesirable material, must be removed if the grain is to go into certain processes. By the nature of its purposes, cleaning produces a large amount of dust. A preliminary

step in the cleaning process is termed scalping. In this process, the grain is run through a coarse mesh screen in shaker or reel form, to remove sticks, stones, stalks, strings, and similar offal. The grain is usually poured through the screen at low velocity with little or no aeration; very little dust is generated. The shaker type of scalper may be of dust-tight design with no vent to the atmosphere. Another step is called aspiration. Crosscurrents or countercurrents of air are directed through dispersed falling grain. The process is designed to separate field dust, fibres, chaff, and light trash from the grain. The third step employs a stack of several grading shaker screens to classify the grain. Mixed grains are separated at this point. Noxious weed seeds are also removed, to prevent them from being disseminated. The three steps of cleaning may be accomplished in separate devices or all in one piece of equipment. The latter commonly employs three integral blowers and has two exhaust airstreams that carry away different types of separated materials.

Emissions

19.42 The solution to a serious air pollution problem from a feed and grain plant is either relocation in a less sensitive area or the initiation of a comprehensive dust control program.

19.43 Pertinent to the control of dust inside plants is the ever-present spectre of fire, sometimes spontaneous. The destructive force of cereal dust explosions is well known, especially the secondary type of explosion that occurs after a primary shock wave has lifted and mixed heavy dust deposits with air, creating a massive, explosive mixture. The vacuum cleaning of mill interiors is, therefore, a constant, expensive chore.

19.44 Feed materials and field run grains commonly contain much fine dust in addition to long, fibre-shaped dust particles, and no reliable prediction of the kind and amount of dust in a shipment of field run grain may be expected. The amount of dust found in many other miscellaneous feed materials varies far more widely than in grains. The long-fibred dust particles, such as barley beards and even weed seeds and other particles, are much more an expected, characteristic part of any particular grain shipment. These, however, seldom present an air pollution problem.

19.45 Table 19-1 presents the particle size distribution of dusts from a boxcar of barley received in a deep hopper at a feed mill. Dust picked up by a control hood was carried by a blower to a cyclone where the larger particles dropped out and were collected in a sack (sample No.1). The cyclone then vented to a baghouse, which collected the finer material in a hopper (sample No.2).

TABLE 19-1 PARTICLE SIZE ANALYSES OF THE PRIMARY CYCLONE CATCH AND THE SECONDARY BAGHOUSE CATCH OF DUST FROM A RAILROAD RECEIVING HOPPER HOOD CONTROLLING THE UNLOADING OF A BOXCAR OF FEED-TYPE BARLEY^a

Particle size, μ	Particle size distribution by wt	
	Sample No. 1 cyclone bottoms, %	Sample No. 2 baghouse hopper, %
0 to 5	0.9	4
5 to 10	0.9	25
10 to 20	3.9	66
20 to 44	9.3	5
44 to 74	12.9	0
74 to 149	16.2	0
149 to 250	5.4	0
Over 250 (60 mesh)	50.5	0

^aSpecific gravity of both samples was 1.4.

19.46 The dusts that cause air pollution problems in receiving, handling, and storing operations are generally the fine dusts found in field run grains, or in those feed materials from which much dust is generated. When one of these materials is unloaded from flat bed trucks or boxcars to deep hoppers, it is dropped from a height of 3 to 15 feet in sudden surges. The particles in the stream of free-falling material disperse as they accelerate, and inspirate a downward-moving column of air. When the mass hits a hopper bottom, the energy expended causes extreme air turbulence, abrasion, and de-agglomeration of the particles. A violent generation of dust occurs. It forms an ascending column that boils out of the opposite end of the hopper. A dust plume of 100 per cent opacity and of sufficient volume to envelop a boxcar completely may be formed from the unloading of grain. Figure 19-11 shows how dust is generated during the dumping of grain from a boxcar into a deep hopper.

19.47 Conveying equipment does not usually present difficult dust problems; however, the rubbing friction of screw conveyors, drag conveyors, and bucket elevators on feed and grain abrades these materials, creating fine dust particles. Dust is generated at the transfer points of enclosed conveying equipment, carried through bucket elevators, and emitted at the discharge of the conveyed materials.

19.48 Belt conveyors are the most efficient type of handling equipment, especially for large volumes of material and for long conveyances. They cause less mechanical abrasion of the material and separate much less of the dusty fines from the grain than screw conveyors do. Dusty air, however, is usually generated

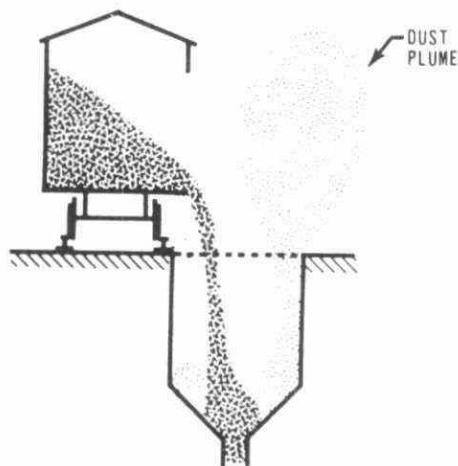


Figure 19-11 Unloading a boxcar into a deep receiving hopper.

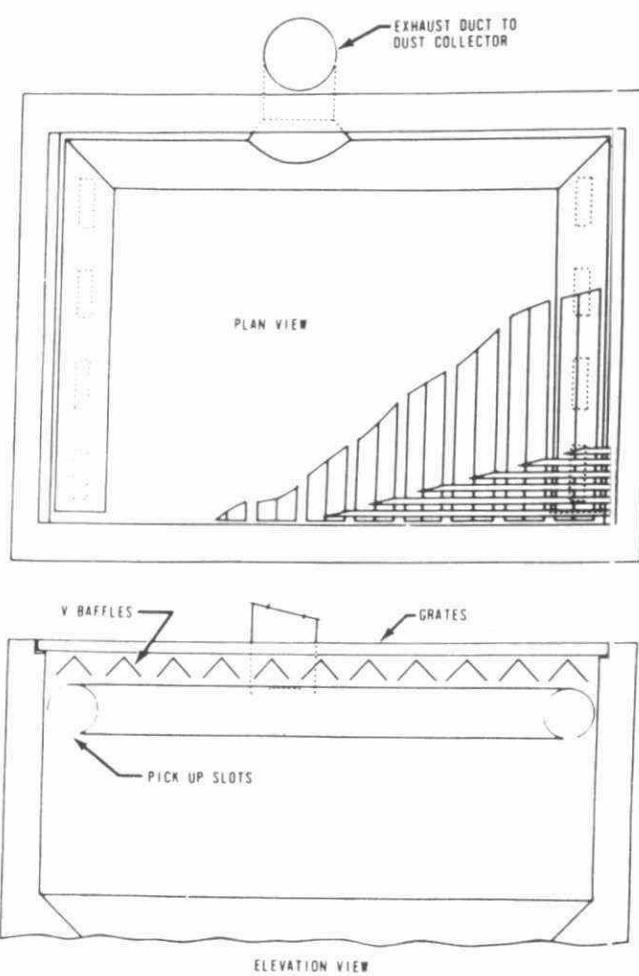


Figure 19-12 Dust control hooding of deep receiving hopper.

at belt transfer points, resulting from aeration of material as it falls onto or away from a belt. A secondary problem with belt conveyors results from materials adhering to the belt as it turns around the head pulley. These particles, usually coarse, drop from the returning belt along its entire length.

19.49 Storage bins vent dust-laden air originating from two sources. One is air displaced by incoming material that falls freely from a spout at the top of the bin, mixing dust with the air in the bin. The other is air inspirated by the flow of incoming material. This air may contain large quantities of dust.

19.50 Shipping feed out of the plant, by spout loading into cars or trucks, is similar to the storing operation. Most finished feeds are, however, somewhat agglomerated by molasses or oil additives so that a minimum of dust is generated in the shipping process. Dusty feeds, of course, require special handling when they are bulk loaded into carriers.

Hooding and Ventilation Requirements

19.51 Hooding requirements in a feed mill are limited to those for deep receiving hoppers, open conveying equipment, and formulating hoppers in which the material free falls without being enclosed. No hooding is required for choke-feed hoppers, enclosed conveying equipment, bins, or for any of the manufacturing processes.

19.52 A preferred method of hooding a deep receiving hopper, to control dust emissions, is to exhaust air

from below the grating. As shown in Figure 19-12, a hopper with V-shaped baffles below the grating is vented to control equipment. The baffles reduce the area open to the atmosphere and also reduce the air capacity required to vent the hopper face. If the hopper is in a building, or completely sheltered from winds, an indraft velocity of 100 fpm through the open area of the hopper, between baffles, may be effective. If moderate winds of 3 or 4 mph are to be encountered, an indraft velocity of 300 fpm may be required. For higher winds, fence-like baffles around the top of the hopper may be required, to prevent the winnowing action of strong wind currents across the hopper grating.

19.53 In a fully enclosed materials-handling system with one or more conveyors and elevators in series, dust-laden air may be conducted through the entire system and emitted at the location of the final material discharge. Connecting a duct to the last piece of equipment in order to vent the entire system to control equipment is, therefore, desirable.

19.54 The feed-processing machines do not commonly require accessory hoods for picking up their effluents. The hooding is an integral part of most basic machines. Cleaners and hammer mills, additionally, have integral blowers that may be vented to the control equipment. Pellet and rolled-grain coolers are designed with integral hooding. The air capacity is based upon the requirements for cooling and drying of the heated feed material only. Floor level cut-in hoppers or scale hoppers may be hooded and vented to control equipment. On the assumption they are inside a building, 100-fpm face velocity into the hood should be adequate.

Air Pollution Control Equipment

19.55 Air pollution from feed and grain mills consists entirely of dusts. These dusts, though varied, may be collected by inertial devices and fabric filters. In practice, all the collected material may be returned to the process. Cyclones may be adequate as dust control equipment for feed plants in farm or nonsensitive areas. Elsewhere, in urban or sensitive communities where complaints and air pollution regulations take effect, baghouses are needed for final dust control of feed plants.

19.56 Table 19-2 shows the results of three tests for determining the loss of grain dusts from cyclone outlets to the atmosphere.

Table 19-2 DUST LOSSES FROM CYCLONES

Grain	Malted barley		Feed barley	Milo	
Basic equipment	Grain cleaner		Hammer mill	Grain cleaner	
Process wt, lb/hr	Test No. 1	Test No. 2	10,350	11,250	
	53,000	50,000		First cyclone	Second cyclone
Exhaust air volume, scfm	2,970	2,970	3,790	3,680	2,610
Dust concentration, gr/scf	0.194	0.160	0.488	0.058	0.006
Dust loss, lb/hr	4.95	4.07	15.8	1.83	0.13

Receiving, Handling, and Storing Operations

19.57 The deep free-fall type of receiving hopper is not normally controlled in farm or nonsensitive areas.

In urban areas it may be adequately controlled only by a baghouse or cyclone-baghouse combination.

19.58 Dust emanating from pneumatic unloaders, pneumatic conveyors, belt conveyors, and elevators need not be collected in nonsensitive areas. Otherwise, baghouse control is needed in urban areas.

19.59 Storage bins and shipping containers need no control in nonsensitive areas. Elsewhere the two applicable control methods are (1) to exhaust the bins and containers by duct connection to baghouse control systems, or (2) to employ some form of a filter vent attached directly to each bin or shipping container.

Feed-Manufacturing Processes

19.60 In urban or sensitive areas, grain cleaner and hammer mill cyclones and cut-in hopper hoods need to be controlled by baghouses. In undeveloped areas, cleaner and hammer mill cyclones may be vented to the atmosphere. If, however, much grain is to be ground in a hammer mill, the use of a baghouse to prevent economic loss may be feasible.

19.61 The hot, moist, agglomerated particles in rolled-grain cooler exhausts or in pellet cooler exhausts are adequately controlled by a cyclone in any type of area, though condensed water vapour plumes from the cyclone are very noticeable under high-moisture and cold-weather conditions.

OTHER VARIED INDUSTRIAL PROCESS SOURCES

Fabricated Metal Products

19.62 Manufacture of a large variety of products:

Heating and plumbing equipment, tools and hardware, structural metal products, cutlery, metal stamping and coating, lighting fixtures, tin cans and others. Usually involves metal melting from ingot; machine shops, metal finishing, and surface coating.

Metals melted are usually refined, and melting operations are easily controlled. Principal air contaminants are metallic fumes and dust from foundries and solvent dust and vapours from application of protective coatings in finishing departments.

Machinery

19.63 Machining and finishing of component machinery parts and/or their assembly in the production of a wide variety of mechanical equipment:

Farm implements, machine tools, printing, office and store equipment, oil field production and refinery equipment, textiles, shoes and clothing equipment, construction equipment, household equipment, apparatus and supplies for the generation, storage, transmission, and utilization of electrical energy, principally electrical motors and generators.

Primarily problems are concerned with dusts and mists from finishing departments, and smoke and fumes from quenching in tempering and heat treating.

Furniture, Lumber and Wood Products

19.64 Logging and milling, including veneering, planing, and plywood manufacturing, box and container manufacturing, sawdust and other by-product manufacturing. Furniture manufacturing, household office and store fixtures, involving production woodworking.

Problems are usually concerned with fines and dusts from milling operations, paint and solvent emissions from surface coating, and smoke from burning waste lumber, mill ends, fines and sawdust.

Transportation Equipment

19.65 Manufacture and/or assembly of component parts for ships, automobiles, rolling stock, aircraft and other transportation equipment involving fabrication of structural assemblies and components, and, in the case of ships and rolling stock, rivetting, welding and sheet metal work. A high degree of specialization, especially in automobiles and aircraft, necessitates extensive subcontracting activities, or concentration of many captive industries into co-ordinated production systems.

Aside from assembly lines which are not in themselves significant sources of air pollution, captive subsidiary operations may involve foundries, heat treating, woodworking, plating, anodizing, chem-milling and surface coating operations which contribute all types of air contaminants, including organic vapour emissions from the application, drying and baking of protective coatings.

Chemicals and Allied Products

19.66 Manufacture of almost unlimited variety of products: petro-chemicals, heavy or industrial chemicals such as sulphuric acid, soda ash, caustic soda, chlorine and ammonia, pharmaceuticals, pesticides, products of nuclear fission, plastics, cosmetics, soaps, synthetic fibres, such as nylons, pigments, etc. Manufacturing techniques encompass virtually the entire chemical technology.

Chemical technology makes possible all forms of pollution, including the emissions of the chemicals (both chemical and end product) and the derivative or reaction products of the chemicals in process or in the atmosphere.

Textiles

19.67 Includes milling and manufacturing of yarns, threads, braids, twines, fabrics, rugs, apparel, lace, and vast variety of products involving processes of spinning, spooling, winding, weaving, braiding, knitting, sewing, bleaching, drying, printing, impregnating, batting, padding, etc.

Lint and fines are emitted from production waste; organic vapour emissions or other mists from dying, bleaching, impregnating, cleaning; smoke from combustion equipment required to power weaves, looms and other processing and conveyor equipment.

Rubber Products

19.68 Manufacture from natural, synthetic or reclaimed rubber, rubber products such as tires, rubber footware, flooring, etc. Processes

involve mastication, mixing or blending of crude rubber, reclaim or chemical rubbers, tubing, binding, and cementing, curing, etc.

There may be local dust and carbon black emissions from mixing and rolling operations, but they are usually under careful control. Problems may arise from organic vapour emissions from solvents used in bonding and cementing, coating and drying of products.

Printing and Publishing

19.69 Printing and publishing by means of letterpress, lithography, gravure, or screen, book binding, typesetting, engraving, photo-engraving and electro-typing. Involves lead melting pots for type-setting machines, and significant quantities of inks containing organic solvents.

Lead oxide emissions are possible from lead pots, but these are easily controlled. Organic solvent emissions arise from the large volumes of inks used, particularly in rotogravure processes.

Food and Kindred Products

19.70 Includes the slaughtering of animals and the curing and smoking of meat products, as well as the preparation of all other food, such as dairy products, canning and preserving of fruits, vegetables and sea foods; grain and feed milling, baking, preparation of beverages, including coffee, beer and other alcohols; animal rendering, manufacture of fats, oil, grease, tallow, etc.

Problems are most notably concerned with odours, particularly from rendering operations and from poor housekeeping where products are permitted to decompose on the premises. Odours may also occur from the handling of by-products, and from coffee roasting.

SUBJECT:

TOPIC: 20

INDUSTRIAL ABATEMENT -
AIR MANAGEMENT

AIR POLLUTION FROM
SEWAGE TREATMENT

OBJECTIVES:

The trainee will be able to:

1. Sketch a flow diagram of an activated sludge sewage treatment plant, indicating potential odour sources;
2. State the basic causes of odours originating from waste water treatment;
3. State the three ways in which odours can be controlled in the order of their technical desirability;
4. Briefly describe methods of odour prevention or removal under the following headings:
 1. Prevent uncontrolled anaerobic conditions
 2. Prevent algae formation or micro-organism formation
 3. Confinement of odours
 4. Chemical treatment of waste water
 5. Treatment of collected gases
 6. Biological treatment of odorous gases
 7. Activated carbon
 8. Combustion
 9. Masking or counteracting
 10. Other techniques.

AIR POLLUTION FROM SEWAGE TREATMENT

Introduction

20.1 The adequate treatment of sewage is one of the most important responsibilities of municipalities.

Sewage is composed of water, organic and inorganic material, and living organisms (bacteria). The main objectives of a sewage disposal system are:-

1. to remove organic material
2. to eliminate disease producing agents.

In the past, contaminated water has played a large role in the spread of disease. In the 19th Century, several European cities built closed conduits for collecting human wastes and discharged these wastes to nearby rivers and streams.

At about the same time, epidemics were traced to water supplies originating from these rivers and streams. It was discovered that bacteria in sewage caused diseases such as typhoid fever, dysentery, and cholera. The treatment of sewage thus became a necessity.

Sewage contains countless numbers of living organisms most of them too small to be visible without the aid of a microscope. They are a natural living part of the organic matter found in sewage and they are important because they are one of the reasons for the success of our present treatment processes. Generally, the microscopic living organisms in sewage are bacteria and other more complex higher forms of organisms.

Many sewage bacteria are normal inhabitants of the intestinal tract of man and animals. Occasionally, disease causing bacteria are included among them. For example, a disease caused by this type of bacterium is Typhoid Fever; on the other hand, coliforms are normal inhabitants of the intestines and are not generally harmful to health. These and other bacteria are destroyed in nature through the activities of higher forms of microbial life. Together, the organisms play a major role in degrading or breaking down organic matter (dead plants and animals and their wastes). By harnessing these organisms under ideal conditions, as in sewage treatment plants, the breaking down of organic wastes can be speeded up and controlled.

Sources of Sewage

20.2 In nature, sewage is present as the waste by-product of human and animal life. Man has added to this the waste products of industrial and commercial activity, so the composition of sewage varies widely in both quantity and quality.

Domestic wastes are those that originate in the bathroom, the kitchen and the laundry room. Once they reach the municipal sewer and combine with any industrial and/or commercial wastes, they are called sanitary or raw sewage. Normal sanitary sewage is easily treated in a well designed, well operated and well maintained sewage treatment plant that is operating within its approved design capacity. Industrial and commercial wastes contained in the sanitary sewage may sometimes be unacceptable for treatment in a municipal sewage plant. In these cases they must be pre-treated before they are discharged into the sewers.

Figure 20-1 is a schematic diagram of a typical conventional activated sludge plant. Primary treatment is used to remove settleable solids from the raw sewage entering the primary clarifiers. The liquid leaving these tanks, called primary effluent, may then be disinfected and discharged to a watercourse or directed to aeration tanks, the first stage of secondary (biological) treatment. The organic matter in the primary effluent serves as food for large numbers of organisms (activated sludge) in these tanks. With adequate oxygen, the organisms use the food for energy and reproduction.

The contents of the aeration tanks, called mixed liquor, then flow into secondary clarifiers where the organisms are allowed to settle and the clear liquid (secondary effluent) is either disinfected and discharged, or directed to a tertiary treatment process. The settled activated sludge is returned to the aeration tank for re-use, with waste sludge directed to the primary clarifiers. Tertiary treatment further removes solids and organic matter, using processes such as lagooning, filtration, or chemical treatment and clarification. Before being discharged to any stream or waterway, the effluent is always treated with chlorine or some other disinfectant to destroy any remaining disease-causing bacteria.

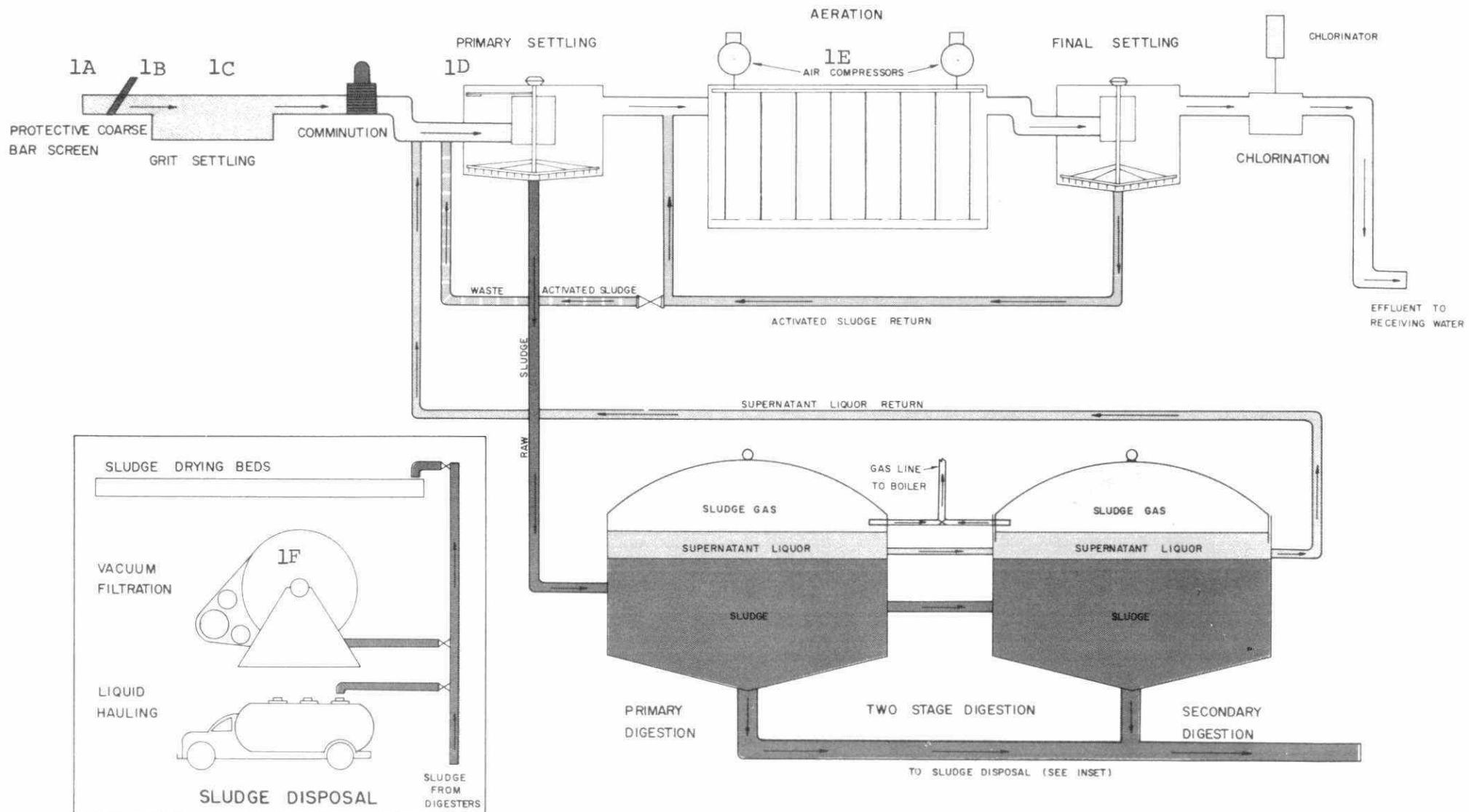
Raw Sewage Characteristics

20.3 Sewage is approximately 99.9% water, with between 800 and 1,600 ppm solids. The sewage may also contain dissolved gases and living organisms. Fresh raw sewage may normally contain from 10 to 200 million bacteria per 100 millilitres. Some are harmful to humans and others are not. Complete secondary

FIGURE 20-1

SEWAGE TREATMENT

BY THE
ACTIVATED SLUDGE PROCESS



treatment reduces these numbers by 80 to 95%, with effluent chlorination increasing the percentage "kill" to 99.9% or better when the treatment plant is operating efficiently.

Inorganic and organic substances which can be seen in sewage are known as suspended solids. These are the solids which can be removed from the sewage by physical or mechanical means, such as sedimentation or filtration. Those that are not seen are classified as dissolved solids. Total solids, as the name implies, include all the solids contained in sewage.

Inorganic solids consist of sand, silt, clay, the dissolved minerals and salts in community water supplies and any other inert matter contained in wastes discharged to the sewers. Organic solids are generally of animal or vegetable origin. Some synthetic compounds, however, are also organic in nature. All organic matter consists of hydrogen, oxygen and carbon. These substances may be combined with inorganic nitrogen, sulphur or phosphorus. The principal groups formed are called proteins, carbohydrates and fats. These serve as food for bacteria and higher forms of organisms, resulting in decomposition or decay of the organic matter. Decomposition leads to the formation of carbon dioxide, nitrogenous compounds consisting of ammonia, nitrites and nitrates, and sulphurous compounds such as hydrogen sulphide and various sulphate compounds. These waste products are in turn used by plant and animal life in their growth processes.

The concentration of total solids in medium strength sewage, which consists of all suspended and dissolved inorganic and organic material, is approximately 450 mg/l. This consists of 300 mg/l organic matter (200 mg/l suspended and 100 mg/l dissolved)

in addition to 150 mg/l inorganic matter (50 mg/l suspended and 100 mg/l dissolved).

A primary sewage treatment plant will normally reduce suspended solids by 40 to 60 %. Complete secondary treatment generally will remove 90 to 95% of the suspended solids producing a final effluent with suspended solids less than 15 mg/l.

The standard for determining the organic strength of sewage is called the Biochemical Oxygen Demand or BOD. This is simply a measure of the oxygen used in decomposing organic matter.

The physical characteristics of sewage include temperature turbidity, colour and odour. The temperature varies depending on the water source. However, the resultant raw sewage is always warmer than the water supply.

Raw sewage is very turbid, containing paper, rags, garbage, faeces, sand and silt. The normal milky-grey colour of raw sewage will not be evident if coloured industrial wastes or partially decomposed sewage are involved. Septic or partially decomposed sewage is dark, sometimes black in colour, with a sulphurous smell. Normal sewage smells musty and may be unpleasant to some people.

20.4 The conventional wastewater treatment process can be divided into four major portions:

1. Primary Treatment
2. Secondary Treatment (Activated Sludge Process)
3. Sludge Treatment and Disposal
4. Disinfection

1. Primary Treatment

20.5 Primary treatment devices are designed to remove or reduce in size large solids, grease, scum and grit before any further treatment of the sewage. The removal of these materials protects pumps and other treatment devices from possible damage. The following units are usually associated with primary treatment:-

- (a) Screens (coarse, bar, fine)
- (b) Comminutors (comminutors, barminators, rotogrators)
- (c) Grit Removal Units (channel, aerated tanks, centrifugal separators)
- (d) Primary Settling Tank

(a) Screens

20.6 Screens are used to remove materials which may damage equipment, interfere with the process or which are aesthetically undesirable in the effluent.

(i) Coarse Screens - Commonly called trash racks or bar screens. Coarse screens generally have vertical or inclined bars spaced from 3/4 to 6 inches. These screens are usually installed at an angle to facilitate hand cleaning, but some units are available that can be mechanically cleaned.

(ii) Fine Screens - Fine screens were originally used in place of settling tanks. Presently they are not commonly used in sewage treatment because the mesh will accumulate material and plug very quickly.

(iii) Mechanically Cleaned Screens - Vertical or inclined bar screens are cleaned by a mechanical "rake". The accumulated material on the screen is pulled up the screen and "wiped off" into a hopper. Screenings are regularly removed from the hopper to prevent nuisance odours and ensure adequate capacity for incoming screenings.

(iv) Cleaning Screens - During dry weather periods coarse trash racks should be cleaned daily; during storm periods they should be cleaned two to five times per day, to maintain a free flow of sewage through the process.

(v) Disposal of Screenings - The screenings may be disposed of by burial, incineration, grinding or digestion. Burying and incinerating are the usual methods of disposal because they are the most economical methods.

(b) Comminutors

20.7 "Comminutors", "Barminators", or "Rotogrators", are trade names used by different manufacturers to identify their shredding devices. This piece of equipment is used to shred and grind large material to small enough size to pass through the screens of the grinding unit. Shredders should be installed with a by-pass equipped with a bar screen to facilitate removal of settled material, and allow inspection of the equipment components such as the cutting edges.

Comminuting devices are normally operated continuously and are usually located ahead of the grit removal units.

(c) Grit Removal Units

20.8 Grit such as sand, stones and gravel may find its way into a sewer system and be carried by the sewage to the treatment plant.

Grit removal units are installed after screening equipment in the process to protect mechanical equipment from abrasion, avoid pipe clogging, and reduce the sedimentation load on the primary clarifier. Grit removal devices include (i) grit channels, (ii) aerated

grit chambers, (iii) mechanical units.

(i) Grit Channels - Grit particles will settle faster than organic putrescible solids because they are heavier. Grit channels are usually designed to maintain a velocity of 1 foot per second at design flow, which is usually sufficient to keep the organic matter in suspension while allowing the heavier particles to settle. Grit channels are usually rectangular and velocity control is achieved by installing a weir at the effluent end of the channel.

(ii) Aerated Grit Chambers - Grit chambers using air to separate the lighter materials from the heavier ones are called aerated grit chambers. Sewage flows into the aerated grit chamber and the heavier particles settle to the bottom as the sewage rolls in a spiral motion from entrance to exit. The lighter organic particles eventually "roll" out of the tank. Aerated grit chambers also provide a washing action as part of the separation process and provide a relatively clean, stable grit that will not cause odour problems during storage and handling.

Aerated grit chambers may remove any gases from the sewage, especially hydrogen sulphide, which create odour problems and increases the chlorine demand of sewage. The release of gases and the addition of oxygen reduce odours released during primary treatment.

(iii) Mechanical Units - One such unit not only removes the grit but also washes it. The grit-collecting mechanism is installed in a small, shallow concrete tank, and consists of two structural steel arms fitted with outward raking blades with scoops on the ends. As the rakes revolve, settled grit is plowed outward to the radius where the end scoops collect and discharge it to a hopper.

Centrifugal units in the form of liquid cyclones are also used. The waste water is introduced tangentially into a cylindrical conical housing. The heavier particles of grit are thrown to the outside wall and collected for disposal. The waste water leaves the centre of the housing as overflow.

(d) Primary Settling Tank

20.9 The primary settling tank or clarifier is the most important single facility in primary treatment. Clarifiers are sized on the basis of settling rate and detention time required. The principle of operation is to reduce the velocity of the sewage as it moves through the tank, thereby allowing the settleable solids time to settle out. Floating solids and scum are also removed in these tanks. Sludge solids are directed to digesters or vacuum filters to further render them inoffensive.

Settling tanks assume a variety of shapes; square, rectangular, round and even octagonal. They are designed to operate on a continuous flow basis and are provided with hoppers for the collection of sludge. Most tanks are now equipped with mechanical sludge-collecting devices. They are constructed with substantially flat bottoms and have sludge hoppers with relatively steep sides. Sludge settles to the tank floor and moves with the aid of mechanical scrapers into the hoppers for subsequent withdrawal.

(i) Sludge Withdrawal - Raw sludge should be removed continuously or three to four times a day, to provide a more constant food supply to the organisms doing the work rather than remove all of the daily sludge accumulated at one time.

(ii) Scum Removal - Scum consists of foreign matter that rises to the surface and is formed. Scum must be removed daily, and ideally, lesser amounts should be removed on a continuous basis rather than a large removal at one time.

2. Secondary Treatment (Activated Sludge Process)

20.10 Following primary treatment, the primary effluent contains suspended and dissolved organic materials. If left untreated, these will cause odours and, eventually, pollution. These are the materials removed in the activated sludge process, by a reaction known as biochemical oxidation.

Activated sludge contains many types of bacteria and other micro-organisms so small that they cannot be seen without the aid of a powerful microscope (500X magnification). The bacteria are the smallest and the most important group of micro-organisms in this process, since they are responsible for oxidizing the organic matter. The bacteria, in the presence of dissolved oxygen, utilize the organic matter as food to reproduce and expand the population in a normal life cycle. The other micro-organisms, which are slightly larger and higher life forms, act mainly as scavengers of free swimming bacteria not associated with the sludge.

A good activated sludge should flocculate, should be brown, and normally has an earthy odour. It is a mixture of dead biological cell material, small organic solids, and living micro-organisms commonly referred to as mixed liquor. It is this solids mass which provides the base to which bacteria cling. These bacteria are known as aerobic bacteria requiring oxygen in order to live. In the presence of oxygen, the bacteria are able to break down the complex organic substances in sewage into simpler organic compounds, which in turn are broken down by different

bacteria to nitrates, phosphates, carbon dioxide and water.

The activated sludge process is, therefore, an aerobic process and as such must be supplied with oxygen at all times. Without oxygen, the bacteria will die, the oxidation process will come to a halt and a foul smelling black sludge will be left. In this state, the sludge is said to be anaerobic (that is, lacking oxygen).

Secondary treatment can be divided into three sections:

- (a) Aeration Tank
- (b) Final Settling Tank
- (c) Sludge Recirculation

(a) The Aeration Tank

20.11 The breakdown of organic materials in the wastewater takes place in the aeration tank. This is achieved by bringing the organic materials into contact with the bacteria in the presence of dissolved oxygen long enough to permit the breakdown to occur. The aeration tanks can be square, rectangular or circular and generally are 10 to 15 feet deep. The tank size depends on the volume of sewage to be treated and its ability to hold the incoming sewage for a period of 4 to 8 hours. The tanks are generally made of concrete or steel, although in some very isolated instances wood has been used. Oxygen is dissolved into the wastewater in tanks, either by diffused aeration or surface aeration. It is essential that adequate mixing is provided, so that the activated sludge is maintained in suspension.

(b) Final Settling Tank

20.12 The final settling tank or secondary clarifier receives the activated sludge from the aeration tank. This unit is essential to the activated sludge process since it is here that the micro-organisms are separated from the now purified wastewater, settling in the form of sludge (called activated sludge) at the bottom. The treated wastewater, with only 10 per cent of its original contaminants remaining, flows over weirs to be disinfected before discharge to the receiving river or lake.

(c) Sludge Re-Circulation

20.13 Scraper mechanisms are used in the final settling tank to collect the activated sludge which settled out from the purified wastewater. This sludge is returned to the aeration tank to treat more wastewater.

Factors Affecting the Activated Sludge Process

20.14 Since the bacteria do the work in the activated sludge system, the factors affecting the system are those affecting the bacteria. As with all life forms, these organisms can only live if conditions remain suitable for their growth. The following are the main considerations in maintaining activated sludge:

1. Since the bacteria are aerobic, oxygen must be present for the organic materials to be broken down. For satisfactory operation of the activated sludge process, a dissolved oxygen concentration in the aeration tank of at least 1 mg/l should be present at all times.

2. As with all other life forms, a second requirement is food. In this case, the organics in the sewage provide the food supply for the bacteria. The bacteria themselves are the food for some of the higher life forms. Insufficient food will result in cannibalism amongst the bacteria, while an excess causes a shortage of dissolved oxygen and the growth of filamentous bacteria which are undesirable.
3. It is also necessary that no toxic materials should come into contact with the micro-organisms. The most likely toxic conditions which occur in the waste water treatment process are caused by industrial discharges. The commonest cause is chemicals resulting in pH conditions outside the range of pH - 6 to 8.5, and soluble chemicals such as cyanide, copper, chromium and nickel which are themselves toxic to the micro-organisms. It is essential then, that these chemicals are eliminated before they come into contact with the micro-organisms forming the activated sludge.

3. Sludge Treatment and Disposal

Primary Purpose

20.15 The primary purpose of sludge digestion is to reduce the complex organic matter present in the raw sludge (removed by sedimentation processes) to a simpler non-objective state. Digestion produces a sludge more amenable to dewatering without nuisance, and renders the sludge fit for easy disposal by

lagooning, dewatering on sand beds, incineration and by direct application to farm lands. Digestion also reduces the volume of sludge and in doing so produces gas which can be utilized for heating purposes or gas engine operation.

The Anaerobic Digestion Process

20.16 After sludge is sent to the digestion tanks, the organic materials contained mostly in the solid portion of the sludge, are slowly hydrolyzed and brought into solution by enzymes present in the digester. Under normal conditions of operation, the organic matter is then quickly broken down into volatile organic acids by a group of bacteria commonly called "acid formers". The organic acids are in turn decomposed into carbon dioxide and methane by a second group of bacteria commonly called the "methane formers". Because of this decomposition, the quantity of organic matter actually in solution normally remains low. There is, however, a build-up of certain salts in solution such as ammonia, calcium, and magnesium bicarbonates which result from the breakdown of protein and soap. In a digester, these salts produce the natural buffers, which normally remain fairly constant at about 1,000 to 3,000 mg/l as calcium carbonate, dependent on the sludge concentration.

When unbalanced digestion conditions exist, the methane-producing organisms cannot remove the volatile acids as quickly as they are formed and a build-up of the volatile acids results. This build-up can take place very rapidly, and in a day or two the total concentration of the materials in solution can be more than doubled.

pH ranges from 6.8 to 7.2 have proved effective in maintaining a good digestion process. Experience has shown that digester process failure will be far advanced before the pH will indicate a problem. The volatile acids test has proved more effective in avoiding a process breakdown. Volatile acid concentrations between 200 mg/l and 500 mg/l will indicate satisfactory operation. A change from 300 mg/l to 500 mg/l might indicate a developing problem, but until a concentration of 1,000 mg/l is reached, gas production will remain high.

To prevent a drop in pH caused by an excess of acid, alkaline material such as lime or sodium hydroxide may be added to neutralize the excess acids. The continued use of such neutralizers is questionable as it can cause a process failure because of an ion toxicity factor due to the presence of excessive Na and Ca ions.

Air Pollution From Sewage Treatment

20.17 Odours constitute the principal air contamination problem at many sewage treatment plants. Sewage contains microbiological organisms, organic food and mineral nutrients. This combination is used to advantage in treatment plants utilizing biological processes such as activated sludge and digesters. These are controlled biochemical reactions which should not lead to significant odours under efficient plant operation, provided no odorous industrial wastes are present and separation distances to nearby residences are adequate.

Causes of Odours

20.18 However, biological degradation can take place in the sewer systems and at the head end of treatment plants where oxidizing agents such as air or chlorine

are not added. Exhaustion of dissolved oxygen in sewers leads to anaerobic fermentation in the acid stage to produce such obnoxious products as indole, shatole, cadavarine, mercaptans, amines and sulphides. In a digester these are broken down under controlled conditions. Any odorous gases are collected and burned-oxidized to innocuous end products. Odours in sewers may develop due to biological degradation of accumulations of organic silts, greases and slimes or the presence of noxious industrial wastes. These accumulations generally build up in long, flat sewers flowing relatively slowly. At periods of high flow; e.g. during a rainstorm, a flushing effect is produced, washing these deposits to the plant, creating an over-load and often short-lived odour problems.

The condition and characteristics of the raw sewage entering the plant greatly influence the odours emitted from the plant. The liquid wastes from many industrial activities contain nitrogen and sulphur-containing organic matter, that give rise to odorous products resulting from biological decomposition in the waste water collection and treatment system. Many industrial and commercial waste waters contain odorous dissolved gases which may cause odour problems at the treatment plant. These gases are likely to be released where the waste water is exposed to the atmosphere such as occurs at the influent works, grit removal chambers, weirs of clarifiers, open mixers and diffused air and mechanically aerated treatment units.

In manually cleaned grit chambers, accumulation of excess grit containing organic matter is a common source of odours, as is the exposure of collected grit, screenings or grease. Anaerobic conditions can arise in any unit of a treatment plant if not properly designed, maintained or operated.

Sludge is also a source of odours, particularly if drawn to drying beds or lagoons before digestion is complete. These odours are difficult to control unless drying is fast and rainfall does not occur. The earthy, tarry odour of well-digested sludge is not generally considered to be a problem.

Incineration or mechanical drying of sludge has led to some odour complaints, particularly the pungent acid-like, burnt cork odour of decomposed proteins when proper operating temperatures are not maintained in the incinerator. Dust is also a problem with some sludge drying equipment.

Although most odour problems result from treatment units or from upsets in the activated sludge process, even when aerobic waste treatment units emit odours and, in some instances, these odours have affected large numbers of the population. The activated sludge process produces innocuous end products, that are inoffensive, and these do not cause any problem from an air pollution standpoint. The odours from aerobic treatment units that do cause problems result from the volatilization of complex organics and intermediate compounds produced during aerobic stabilization. The combination of these compounds produce a characteristic musty/earthy odour that is present at all treatment plants and many people find the odour objectionable.

This odour characteristic is similar in most waste water treatment plants, however, it varies in intensity depending on raw waste water properties, type and size of the treatment plant and, local conditions. Due to the comparatively small size of most plants, the odorous compounds usually dissipate rapidly and do not normally cause odour complaints. But, under adverse weather conditions, such as an air inversion, the atmosphere surrounding large plants

may not have sufficient capacity to disperse the odorous gases before they reach residential areas. Even though of low intensity, it does appear that this source has caused some odour problems from one and probably two treatment plants. It is expected that, in the future, it will be necessary to cover the aeration tanks and other sections that may be contributing to odour problems and ventilate these locations to a common deodorizing chamber for treatment.

To summarize, the basic causes of odours experienced in Ontario originating from waste water treatment are these:-

1. Odorous gases from anaerobic biological processes or incompletely completed aerobic processes in liquid wastes or sludges. This includes hydrogen sulphide, mercaptans, organic sulphides, ammonia, decayed bacteria, partially oxidized complex organics or amines;
2. Odorous gases from certain types of algae, which can grow in some parts of a treatment facility;
3. Odorous gases from incomplete or improper oxidation or combustion of sludges in sludge incinerators;
4. Evaporation of gases from exposed screenings or improperly washed grit from the degritting process;
5. Bad housekeeping and poor plant operation and maintenance.

Location or Sources of Odour

20.19 If a sewage plant is not properly designed or correctly operated, there can be sources of odours and odour emissions. There are many places or unit processes in the treatment of sewage where such odour can be generated. This section lists some typical, or potential sources, but this list is not complete. The specific locations, which are described below, are identified on the flow sheet for a typical sewage treatment plant. Figure 20-1 shows a schematic diagram of a biological treatment process with diffused air aeration, sludge dewatering and sludge disposal. The numbers on the figure refer to locations for potential odour sources and these numbers correspond to the numbered sections below.

Sewage Entering Plant

20.20 Raw sewage (1A), particularly when it has been in a sewer for extended periods, can be very odorous, usually because of anaerobic reactions. Certain industrial wastes, when mixed into the sewage, can contribute to the variety, intensity and prevalence of odour emissions; this includes, for instance, meat, food and fish processing wastes, tanning, wool scouring or brewery wastes.

Screening processes (1B) take the larger sized solids out of sewage and thus expose them to air. The placement of primary clarifiers and screens into enclosed housings has minimized the odour by preventing air from directly carrying them to adjacent communities. If the sand, gravel and often heavy items, metal pieces, glass etc. obtained in the degritting operation (1C) are not clean, but contain appreciable organic material, they can become a source of odour.

When the sewage flows over weirs, such as the weirs in primary settling tanks (1D), the volatile odorous gases will escape readily. Improper design or operation of the primary clarifier often leads to odour generation.

Evaporation of Droplets

20.21 Activated sludge processes (1E) often use aeration methods which create a fine spray or bubbles and trickling filters which cause droplets to be formed. Evaporation of water from small droplets causes aerosols to be formed, such as those containing bacteria, salts or suspended solids.

In ammonia stripping (basically a reverse scrubbing process to remove nitrogen in the form of NH_3 at high value of pH) it is possible to release organic odours in addition to producing NH_3 , by releasing odour materials from small droplets.

On occasion a foam is created on the surface of the water in the secondary treatment of sewage or in the mixing of chemicals into the water. The collapse of the individual foam bubbles can create aerosols. Often fine water sprays are used to confine the location or break foam bubbles; this tends to augment the momentum of the droplets formed by bubble collapse and thus augments aerosol formations.

Ponds Storage or Holding Basins

20.22 These can become quite smelly if anaerobic conditions are allowed to occur in an uncontrolled manner. Ice formation on pond surfaces in the winter can limit the amount of oxygen transferred into the water; this can contribute to anaerobic conditions. Proper exposure to air and some agitation or mixing is usually very effective in preventing odours.

Sludge Handling and Processing

20.23 The exposure of improperly treated sludge or sludge cakes to the atmosphere can allow odorous volatile materials to escape to the atmosphere. Raw sludge can yield a strong ammonia odour, especially when lime-treated. These can occur in open sludge conveyors, filters, trucks, drying beds, etc.

Figure 20-1 shows a vacuum filter for dewatering sewage sludges, (1F)

Sludge Incineration

20.24 When improperly designed or operated, a sludge incinerator can fail to completely oxidize or burn the sludge causing odorous compounds in the exhaust gas.

Multihearth furnaces have been very effective in burning sludge cakes, in cleaning and reactivating activated carbon and recalcining and thus reclaiming lime, which is becoming a popular chemical for the treatment of sewage.

In most multihearth furnaces, the upper one or two hearths are used to dry the incoming sludge material, drive off the moisture and thus recover heat from the hot gases. The next several hearths will generally drive off volatile organic compounds, which are burned with air and create heat; subsequently, the lower hearths are usually operated at the highest temperature, causing pyrolysis and oxidation of the remaining organic materials and the gradual cooling of the ash. The ash is usually free of odours and sterile, unless combustion or pyrolysis have not been completed. Normally, a combustion zone temperature of 680°, to 760°C is adequate to decompose odorous materials; and odours in the exhaust gas, even at 425°C, are not apparent. The exhaust gases contain both particulates and gaseous impurities and these gases are normally put through a wet scrubber.

Sewers

20.25 While not normally a part of a waste water treatment plant, sewers are the means for transferring municipal waste water from the homes and industrial sources to the treatment plant. Improperly designed sewers allow waste water to accumulate and anaerobic, odorous conditions can occur. Odours can readily escape from sewers through holes in manhole covers and vents of pumping stations.

Methods of Odour Prevention or Removal

20.26 The control of the odour emission can be accomplished more effectively if the exact identity of the specific chemical compounds causing the odour can be determined. Unfortunately, only a relatively small number of specific compounds have been identified, characterized, and an optimum method of treatment or prevention determined. Most of the odours are still not identified; however, several methods for their control have been effective. The technology for the prevention and/or removal of odours from sewage treatment processes is, therefore, still a very empirical art.

There are three ways in which odours can be controlled. In order of their technical desirability they are: (1) changes to the treatment process to prevent the generation of odours, (2) removing odour chemicals and destroying or changing the nature of the odour producing gases or vapours, and (3) emitting a counteracting odour to mask or ameliorate the action of the irritating odour.

There are many techniques for the control of odours in municipal waste water treatment. The selection of the best technique for a given odour problem will depend on many factors, including the

type, intensity, frequency, duration of the odour, the specific chemicals (if known) that cause the odours, their quantity, the local weather conditions, the plant process design, the skill and experience of the operators, the prior experience with the specific odour control process, the capital and operating costs, and the background and experience of the people doing the selecting.

Prevent Uncontrolled Anaerobic Conditions

20.27 A simple technique for preventing anaerobic conditions is to add air or oxygen at or upstream of the anaerobic location. If the incoming sewage stinks badly, a small amount of aeration (with good mixing) in the sewer line upstream of the plant may remedy the problem. The addition of diffused air or a surface aerator to a lagoon which smells badly can assist. However, this must be done carefully, because air can sometimes scavenge the chemicals from the lower layers and actually release additional odours to the atmosphere.

The use of chlorine has been successful because it not only oxidizes and changes the chemistry of odorous compounds, but it also stops or impairs further biological anaerobic activity and thus stabilizes the material.

Often simple agitation or circulation of water in a pond or basin is adequate to prevent anaerobic zones from forming.

Prevent Algae Formation or Micro-organism Formation

20.28 In many holding ponds or treatment basins, the formation of algae readily takes place. Several of these algae form objectionable odour, some of which

have recently been identified as specific organic compounds. For example, certain algae micro-organisms were found to produce isopropyl mercaptan, a very odorous organic sulphur compound. An odorous hydrocarbon compound called geosmin has been identified with several micro-organisms including blue-green algae.

Confinement of Odours

20.29 By enclosing those unit processes which can cause aerosols to be formed and carried away, it is possible to prevent exposure of the surrounding community to odours, aerosolized bacteria or virus. This includes putting housings, hoods or covers over clarifiers, trickling filters, screenings, holding tanks containing digester supernatant, holding tanks from heat treatment process decant liquors, weirs, vacuum filters, etc. Sometimes a foam breaking operation (sprays or mechanical destruction of bubbles) can cause odours through aerosol formation and these areas can also be covered.

Although the mere enclosure of these equipments will be effective in preventing aerosol transport, it can be made even more effective by collecting and treating the gas from these enclosures by some of the techniques described later in this section, such as scrubbing or ozone addition.

The air bubbles formed in aeration or in foams (bubble diameter 1000μ or larger) each create several small droplets when they collapse. Under most atmospheric conditions, these small droplets will evaporate quickly leaving the material that was suspended or dissolved as a solid particle in the air. These particles will settle slowly because of their small size (10 to 15μ).

Chemical Treatment of Waste Water

20.30 The use of chemical additives to odour emitting water can be very effective in reducing odour problems, particularly when odorous organic wastes are present. This includes oxidation or partial oxidation of organic chemicals accompanied perhaps with a simultaneous adjustment of pH. Oxidation can be achieved by aeration (dissolving air in water), admission of pure oxygen, ozone, potassium permanganate, chlorine, chlorine dioxide and other chemicals. Potassium permanganate has been successful in application where there was iron, manganese, hydrogen sulphide and organics.

The addition of inert material such as silt has also been effective in some cases. Many of the odorous organic compounds are absorbed onto the silt and are thus not released.

Prechlorination of sewage ahead of the treatment plant has been effective in reducing odours in many installations, but in a number of cases this treatment was abandoned because of high costs and because sometimes bad odours resulted.

Treatment of Collected Gases

20.31 This concerns wet scrubbing of gases collected from various unit processes within the treatment plant with water, or with water which has chemicals added to it with various types of spray devices or scrubbing equipment, passing the gas through packed columns, adding ozone to the gas or using activated carbon. Typical chemicals added to the water include lime, permanganate, hypochlorite, or chelated iron compounds. While chemical solutions are very effective in removing odours, they are relatively expensive.

Biological Treatment of Odorous Gases

20.32 There have been a number of installations where this type of treatment has been effective and low in cost. Basically, the odorous gas is passed through a bed of living micro-organisms, which cause the decomposition or adsorption of odorous gaseous substances. The process will generally be satisfactory with organic odours and very dilute toxicants, since large concentrations of toxic materials, such as H_2S , and sometimes suspended inorganic solids interfere with the micro-organisms' functions. Nutrients such as organic nitrogen or phosphates may have to be supplied and added to the water.

Activated Carbon

20.33 It is well known that activated carbon will adsorb organic materials, such as those producing odour, and thus remove some smells from municipal waste water or from air. The more advanced sewage treatment techniques use columns of granular activated carbon primarily for the reduction of dissolved organic materials; the removal of odours and tastes is a salutary effect of the use of carbon columns. Recovery and regeneration of granular carbon makes this a fairly economical process.

Powdered activated carbon has been used as an additive to sludge or waste water to minimize odours. Powdered carbon has been added as necessary to a secondary clarification process as a means for controlling odours when they occur on a sporadic basis.

Activated carbon beds are also effective in cleaning collected bad-smelling gases from various parts of the waste water treatment process to remove gaseous odours.

Combustion

20.34 Sludge incineration requires usually the installation of a wet scrubber for cleaning particulates from the exhaust gases. Typically, a multihearth furnace burning sewage sludge will have less than 0.12 grams/sfm of particulates and the scrubber requires between 2 and 5 inches W.G.

Only if a furnace is designed or operated improperly will there be air pollution from the exhaust gas, usually particulates like soot, odours due to incomplete combustion or smelly ash. A similar situation can exist if lime recalcining furnaces are not operated properly. If the thermal-mass balance is upset, e.g. if the cake feed rate suddenly diminishes, then the upper hearths may not just evaporate moisture, but the increased temperature would drive off odorous substances which are not fully oxidized.

Combustion of odorous gases collected from various unit processes is used for assured decomposition of odorous chemicals in off-gases from various industrial processes (e.g. coffee roasting, smoking of meats) and can also be used for burning of odorous gases collected in a municipal plant. Both thermal combustion (addition of heat) and catalytic combustion have been effective.

In installations where there already is an existing furnace, such as a multihearth sludge burning furnace, it is possible to burn odorous gases by using them as combustion air for the furnaces.

Masking or Counteracting

20.35 The release of another odorous chemical in the vicinity of the bad odour release point can help in disguising the unpleasant one. While this method really does not treat or destroy the bad odour, it "fools" the human nose and has been effective in reducing neighbourhood complaints and is relatively low in cost. The matching of a malodour and its counteracting odour is not always easily achieved.

Other Techniques

20.36 The dilution of gases produced in waste water treatment is the simplest and probably the lowest cost process. It is practiced widely and usually not satisfactorily if potent odours are present. Putting odorous gases through a tall stack has in some cases reduced the odour problems in the immediate vicinity of the plant.

Significant odour sources arise from spills, improper sampling procedures, letting waste water stand in pipes or holding tanks, intentional or unintentional by-passing of a portion of the treatment process, etc. This can generally be described as poor operation and improper housekeeping and it can usually be corrected by enforcing discipline and good operating practices.

OBJECTIVES:

The trainee will be able to:

1. List the four steps in the sequence of which the air pollution problem can be considered:
 1. production, 2. emission,
 3. transfer, 4. reception.
2. Name the two basic air pollution control concepts:
 1. concentrate and contain
 2. dilute and disperseand briefly describe the bases of these concepts;
3. List the five control methods available within the two basic air pollution control concepts, and briefly explain them;
4. List the seven categories into which devices for control of particulate matter can be grouped, and briefly explain the principle of each;
5. List the four categories into which devices for control of gases and vapours can be grouped, and briefly explain the principle of each;
6. State the advantages and disadvantages of the following control devices:
 1. low energy scrubbers
 2. high energy scrubbers
 3. bag filters
 4. electrostatic precipitators.

CONCEPTS OF INDUSTRIAL AIR POLLUTION CONTROL

21.1 The air pollution problem can be considered to consist of four steps in sequence: production, emission, transfer, and reception. During each phase, attempts can be made to reduce the danger of contamination and in most cases scientific and technological methods already exist.

There are, therefore, two basic air pollution control concepts, namely:

- (a) concentrate and contain
- (b) dilute and disperse

The concept of concentration and containment is primarily that of the control of the individual pollution source by installation of a properly engineered collection device.

Dilution and dispersion of contaminants is also achieved by the use of tall stacks and the ability of the atmosphere to diffuse contaminants under favourable meteorological conditions. It should be remembered, however, that the dispersal of contaminants in the atmosphere, however useful it may be, does not remove the material but merely dilutes it through an increase in air volume. If most of the contaminants are not removed on a long term basis a condition will eventually be reached, at the present rate of industrial and urban growth, that the lower layer of the atmosphere will become overburdened with contaminants to a limit intolerable to man, animal and vegetation.

Industrial Air Pollution Control Methods

21.2 The control methods available and falling within

the two basic concepts mentioned in the preceding paragraph are as follows:

1. Reduction at the source through raw material changes, or practice or modification or replacement of process equipment.
2. Reduction of contaminant discharge at the source by the application of control equipment.
3. Reduction of contaminant by timed emissions during periods of adverse meteorological conditions.
4. Dilution of the source discharge by the use of tall stacks.
5. Dispersion of source locations through allocation of land usage.

When considering any specific air pollution control method, all efforts should be directed first to the reduction of contaminants at the source, consistent with available technology, balancing risks and benefits with cost of control, before making use of tall stacks for purposes of contaminant dispersion and dilution.

Attention should also be directed to the reduction of contaminants at the receptor by land zoning and land usage.

Air Pollution Control Engineering

21.3 It is intended to present in this topic a brief review only of the various technological and

engineering aspects of air pollution control achieved by the reduction of contaminant discharge at the source, by the application of methods 1 and 2, summarized in the preceding section.

1(a) Reduction Through Raw Material Changes

21.4 Offensive substances may often be eliminated entirely from processes which are causing air pollution by substituting materials which perform equally well in the process but which discharge innocuous products to the atmosphere, or none at all.

Typical examples of raw material substitution are: changing from a high to a low sulphur fuel for the production of heat and power, or for instance, by selecting cold-setting synthetic resins for rubber in the manufacture of paint brushes instead of using rubber, which requires vulcanizing for a period of many hours, causing a severe odour nuisance due to the emission of sulphur-containing volatile products.

(b) Reduction Through Process Change

21.5 Process changes can be as effective as product substitution in reducing or eliminating air pollution emissions.

In the chemical and petroleum refining industries many changes have taken place where because of automation, often computer controlled, completely enclosed systems have been developed that minimize release of materials to the atmosphere. Losses from volatile materials have been reduced by condensation and re-use of vapours, as for example by the use of condensation units on volatile petroleum product storage tanks.

Other examples are: changes from wet to dry processes; garbage compaction instead of incineration; change in fuel, etc.

(c) Reduction Through Operational Changes or Practice

21.6 The mode of operation and scheduled maintenance can bring down emissions to a satisfactory level. This can be seen very clearly, for example, in the case of a diesel engine generator. Here is a unit that should present no pollution problem, but let the engine be overloaded or overfueled and visible smoke appears in the exhaust. Smoke emissions will also be excessive if the fuel injection system is fouled, or worn piston rings develop.

For power engineers, charged with management and operation of existing plants, a major pollution-control concern is furnace combustion in steam generators and incinerators. The process of combustion and its control is illustrated by the diagrams of Figure 21-1.

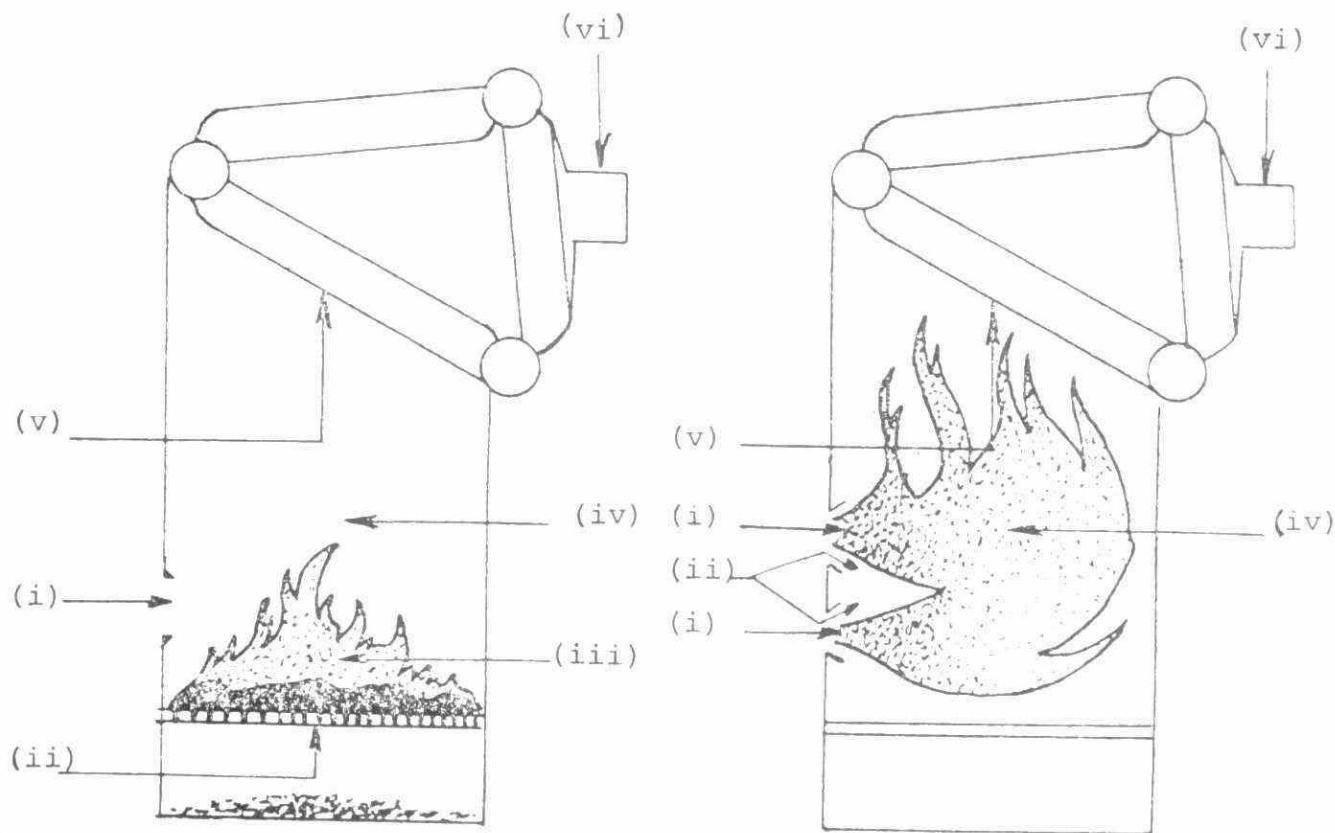


FIGURE 21-1
Cross Section through a typical boiler

(i) Good combustion begins with delivery of fuel to the furnace. In fuel-bed firing, this means selection of fuel type and size to match firing equipment, and maintenance of proper bed thickness. Size segregation must be avoided. In suspension firing, burner must deliver finely divided particles and develop high scrubbing action between fuel and air.

(ii) Air distribution through fuel bed or at burner is vitally important. Unbalanced flow through fuel bed causes uneven combustion conditions; it is particularly important to avoid air leakage at side and through settings. In suspension firing, all air through burner must be carefully matched to combustion needs and distributed to insure intimate mixing.

(iii) Solid fuels include carryover. In fuel-bed firing, partly burned fuel particles and ash may be lifted from the bed by high-velocity air; some fly-ash may form in the combustion space. In suspension firing, all ash appears in the furnace space and the small particle size and turbulence tend to carry a large share of it into the gas stream to the stack.

(iv) The combustion process begun at the fuel bed or the burner moves to a successful conclusion in the furnace space if air and fuel are continuously and vigorously in contact. Turbulence diminishes the possibility of air-fuel stratification, lengthens the time available for the combustion process, and increases relative motion between the air and the fuel.

(v) Smoke and other products of incomplete combustion result if chilling effect of boiler tubes and other "cool" surfaces stops the burning process. Basic answer is ample furnace volume, but the limitations

of undersized furnaces can be overcome in many cases by increased turbulence provided, for example, by suitably located high-velocity air or steam jets.

(vi) Stack emission could include gases such as intermediate hydrocarbons, sulphur and nitrogen compounds; suspended particles or "smoke"; entrained solid particles of ash and unburned carbon. Careful fuel selection and attention to fundamental principles of combustion can eliminate some of these entirely and reduce the amount of others, such as fly-ash.

Application of overfire jets is typical of the practical modifications that can be used to overcome pollution-producing deficiencies in existing plant design. The combustion space within the furnace can also be modified by changing of furnace arches or baffles. Modifications to existing plant might also be interpreted to include a shift from one firing method to another or from one fuel to another.

2. Reduction of Contaminant Discharge by the Application of Control Equipment

21.7 Air pollution control equipment is classified into two groups:

- (a) equipment controlling particulate matter
- (b) equipment controlling gaseous emissions

Particulate Matter

21.8 From an air pollution point of view, particulate matter is any material that exists as a solid or liquid at standard conditions. Small particles tend to go into suspension in air or other gases, forming aerosols. Generally speaking, when particle size is below 10

microns such suspensions are essentially permanent and the aerosol behaves much like a gas. Except where turbulence is extreme, aerosols having particles larger than 44 microns are unstable and the particles tend to settle out in time.

Smoke and fumes are in general stable suspensions of particles visible only in the aggregate, often of submicron size. Smoke is the product of incomplete combustion, consisting mainly of carbon and other combustible material. Fumes may be defined as very small particles resulting from chemical reactions other than combustion, or from the condensation of vapours produced in combustion, distillation or sublimation. They are commonly metals or metallic oxides. Dust is a term applied to a range of solid particles, usually produced by the physical degradation of larger masses. Dust aerosols are frequently of an unstable character. Mists are composed of droplets of vapour that has condensed on suitable nuclei. They are stable when vapour pressure of the particle is low, or when the droplets are in a gas that is saturated.

2 (a) Equipment for Control of Particulate Matter

21.9 The devices for control of particulate matter can be grouped into the following categories:

- (i) settling chambers
- (ii) impingement separators
- (iii) panel filters
- (iv) inertial separators
- (v) wet collection devices
- (vi) bag filters
- (vii) electrostatic precipitators

21.10 Settling chambers are the simplest of collection

- (i) devices which in their common form consist of a long box-like structure in the exhaust system. The velocity of the dirty gas stream is reduced by the enlargement in cross sectional area, and particles with a sufficiently high settling velocity are collected by the action of gravity forces. A very long chamber is required to collect small particles. Limitations of space usually restrict the usage of simple settling chambers to the collection of particles 40 microns or greater. Their greatest use is as a precleaner, to remove coarse and abrasive particles for the protection of the more efficient collection equipment that follows the chamber. Figure 21-2 shows a simple type.

21.11 Impingement separators. When a gas stream carrying

- (ii) particulate matter impinges on a body, the gas is deflected around the body, while the particles, because of their greater inertia, tend to strike the body and be collected on its surface. The bodies may be in the form of plates, cylinders, ribbons or spheres. Two types are shown in Figures 21-2 and 4.

Impingement separators are best used in the collection of mists. The collected droplets form a film on the surface and then gradually drip off into a collection pan or tank.

21.12 Panel filters are mainly used in air conditioning

- (iii) installations, though they do have several industrial applications. The filter pad consists of materials such as glass fibres, hemp fibres, corrugated fibreboard, metal screening, etc. When the maximum allowable dust load has accumulated, the metal trays are removed, washed or

Dynamic collectors

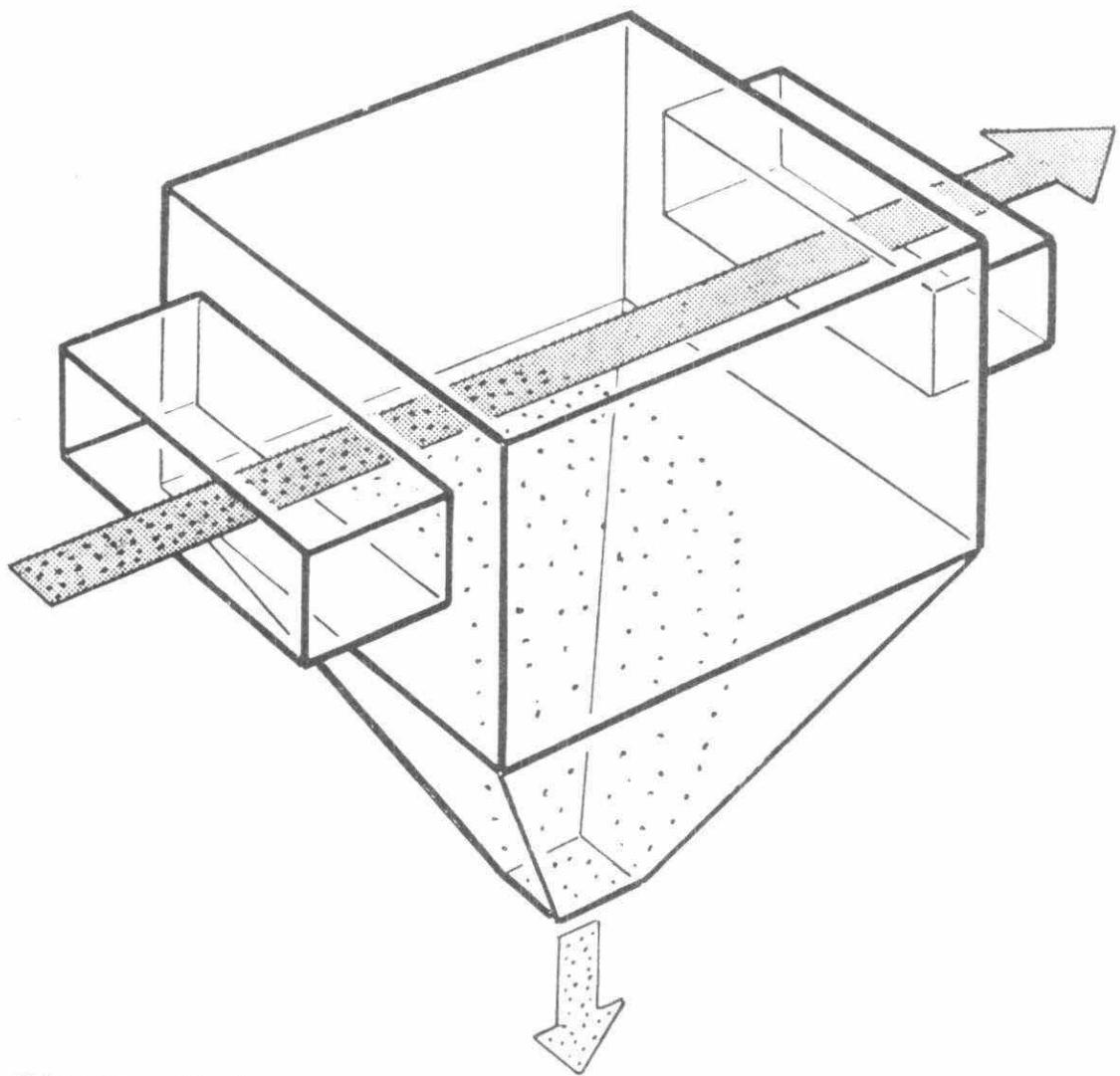


Figure 21-2
Settling chamber

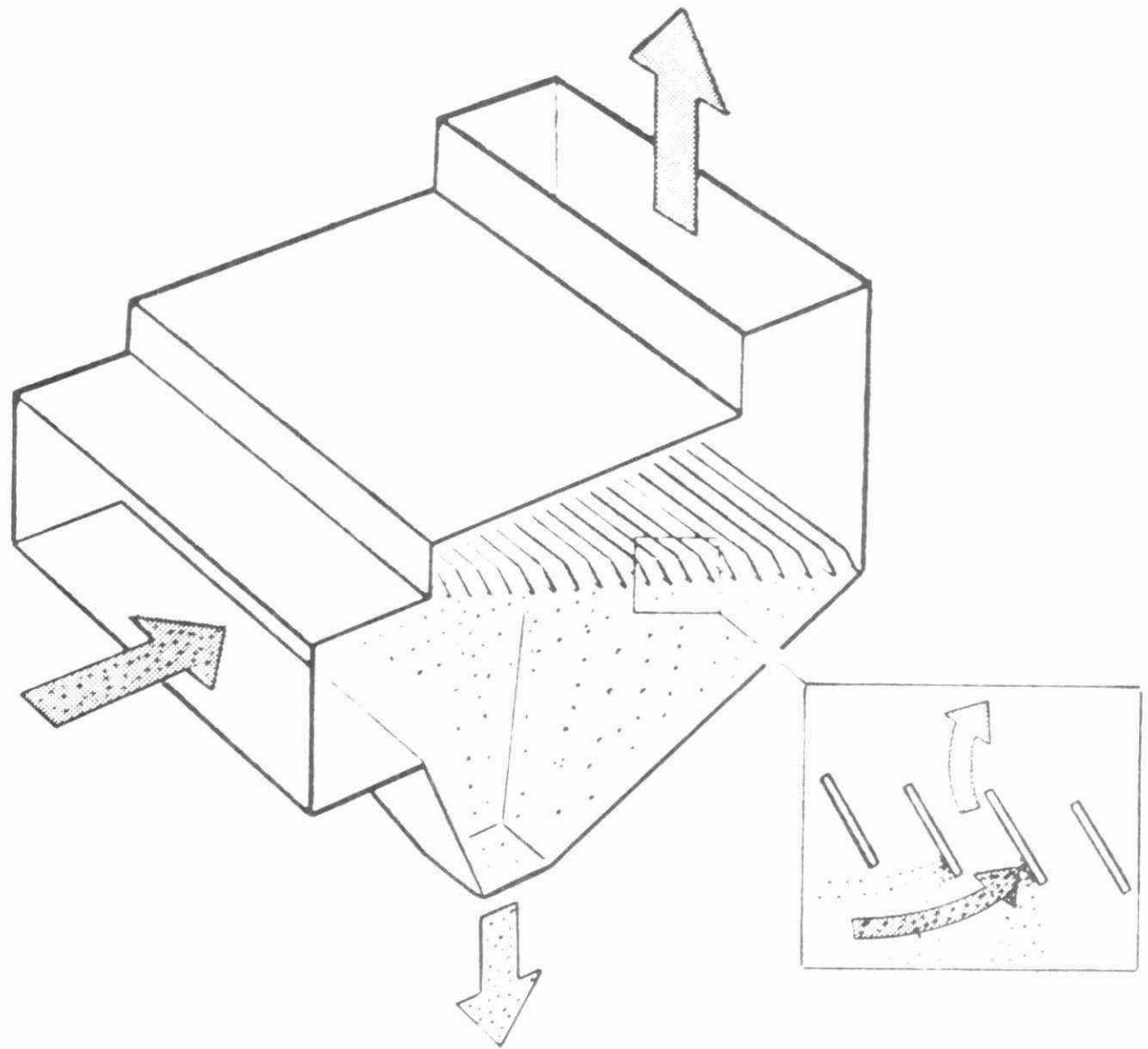


Figure 21-3
Dust louvre

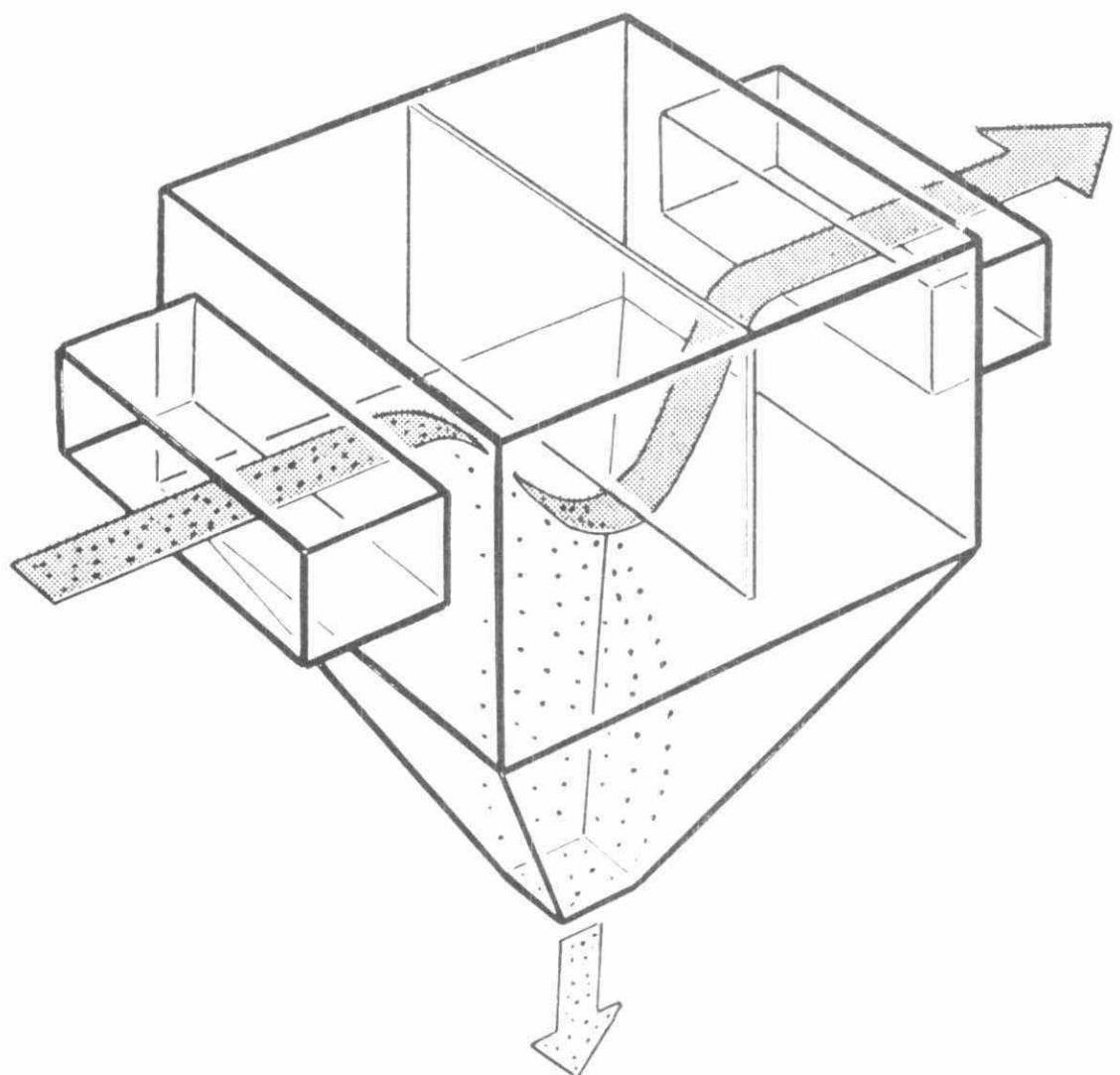


Figure 21-4
Baffled chamber

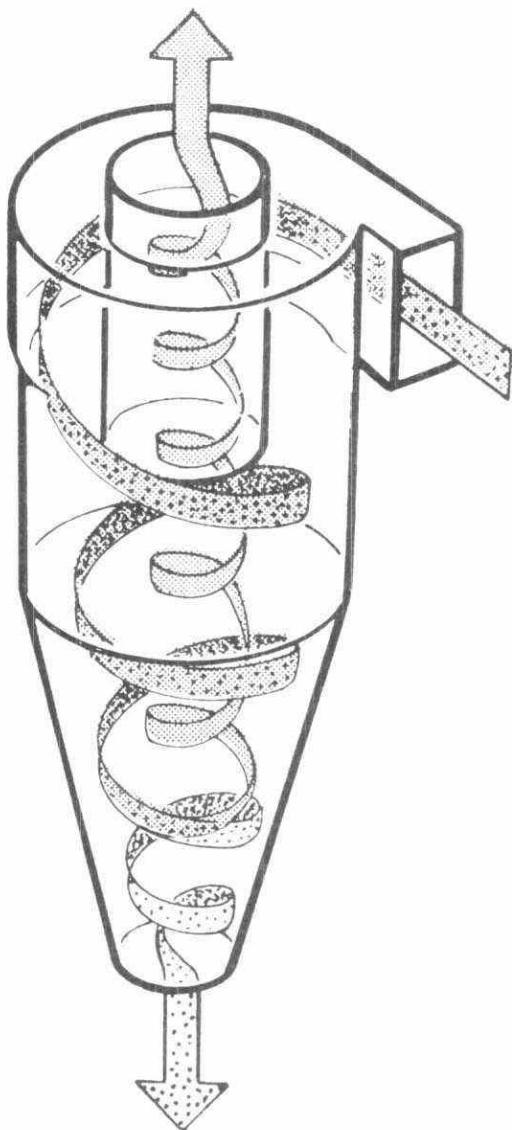
steamed, re-oiled, and put back into service. Other pads are thrown away when they become loaded with dust. A common industrial application of the wire screen-type filter is found in collection of mist generated from cutting oils used by metal cutting machines. Dry filters are frequently used to collect the overspray from paint-spraying operations.

- 21.13 Inertial separators operate by the principle of
(iv) imparting a centrifugal force to the particle to be removed from the carrier gas stream. This force is produced by directing the gas in a circular path or effecting an abrupt change in direction.

A typical cyclone collector is shown in Figure 21-5. The construction of inertial separators is usually relatively simple, and initial as well as maintenance costs are generally low. Collection efficiencies, however, are low. Although suitable for medium-sized particulates (15 to 40 microns), ordinary inertial separators are unsuitable for fine dusts or metallurgical fumes. Dusts with a particle size ranging from 5 to 10 microns are normally too fine to collect efficiently.

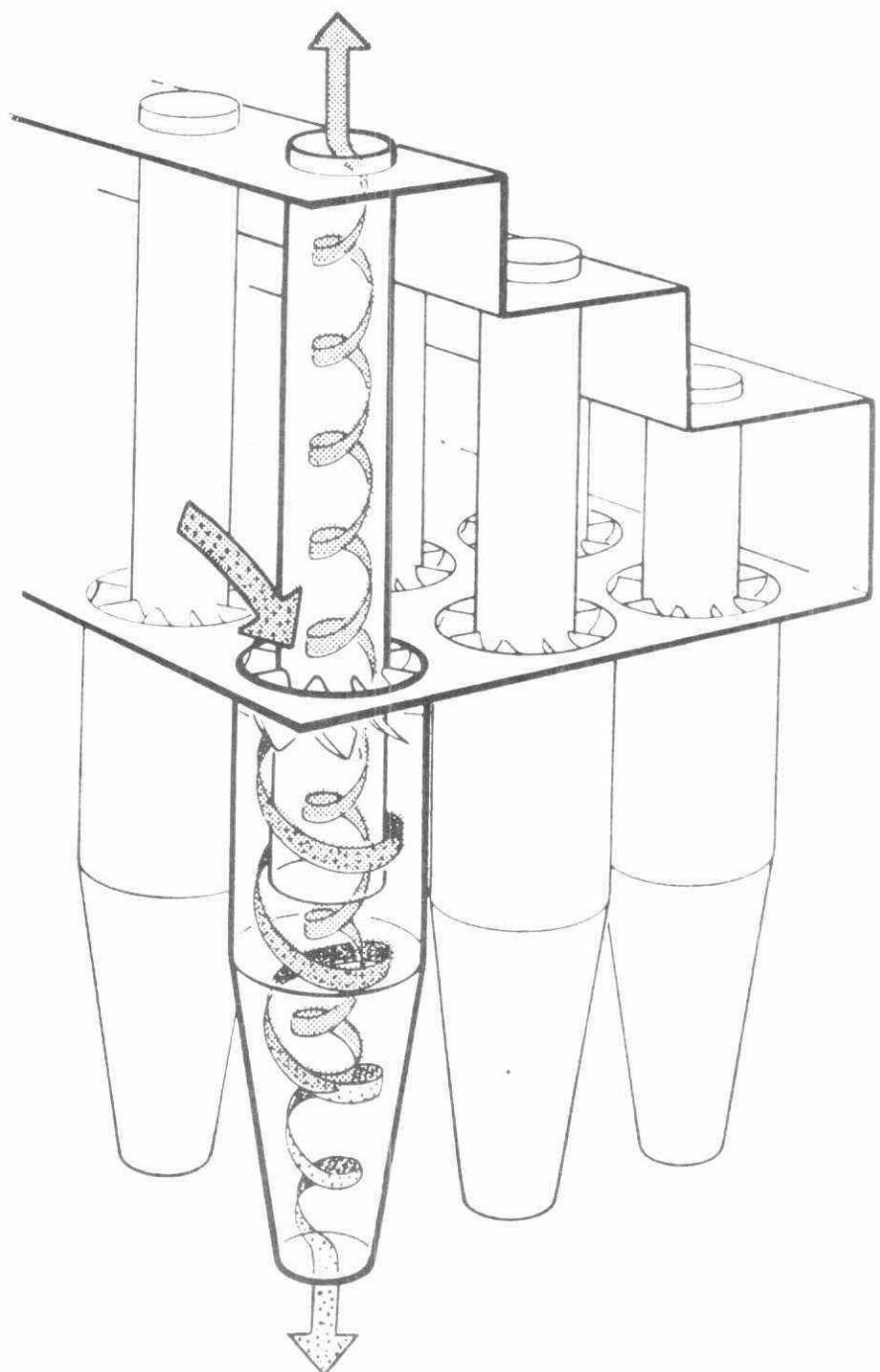
In some cases, however, small diameter, high efficiency cyclones can be effective in collecting particles in the 5 micron range. These are arranged in parallel, having a common gas inlet and outlet, as is shown in Figure 21-6.

The flow pattern differs from that in a conventional cyclone in that the gas, instead of entering at the side to initiate the swirling action, enters at the top of the collecting tube and has a



Cyclone

Figure 21-5



Multi-cyclone with axial inlet

Figure 21-6

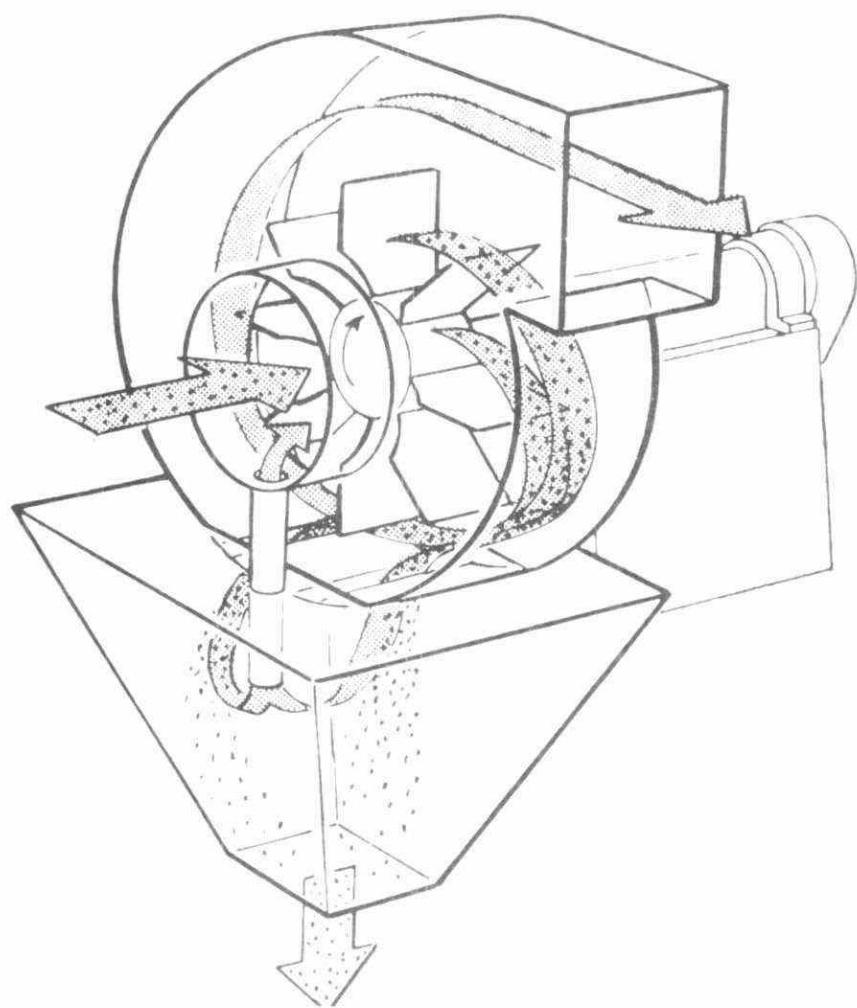
swirling action imparted to it by a stationary vane positioned in its path. The collecting tube diameters usually range from 1 foot to as small as 2 inches. Well designed units can be constructed that have a collection efficiency as high as 90% for particulates in the 5 to 10 micron range.

Collectors are also available in which the centrifugal force is supplied by a rotating vane as is shown by the diagram of Figure 21-7.

This type of unit serves both as an exhaust fan and dust separator. In operation, the rotating fan blade exerts a large centrifugal force on the particulates, ejecting them from the tip of the blades to a skimmer bypass, leading into a dust hopper.

Efficiencies of mechanical, centrifugal separators are a little higher than those obtainable with simple cyclones. These units cannot be used to collect particulates that cake or tend to accumulate on the rotor blades, since these particulates cause clogging and unbalancing of the impeller blades with resultant high maintenance costs and shutdowns.

- 21.14 Wet collection devices use a variety of methods
- (v) to wet the contaminant particles in order to remove them from the gas stream. The basic mechanisms by which liquids may be used to remove aerosols from gas streams are as follows: wetting of the particles by contact with a liquid droplet and impingement of wetted or unwetted particles on collecting surfaces, followed by their removal from the surfaces by a flush with a liquid.



Dry centrifugal collector

Figure 21-7

The simplest type of scrubber is a chamber in which spray nozzles are placed.

Conventional cyclones can be converted by addition of spray nozzles as is illustrated in Figure 21-8.

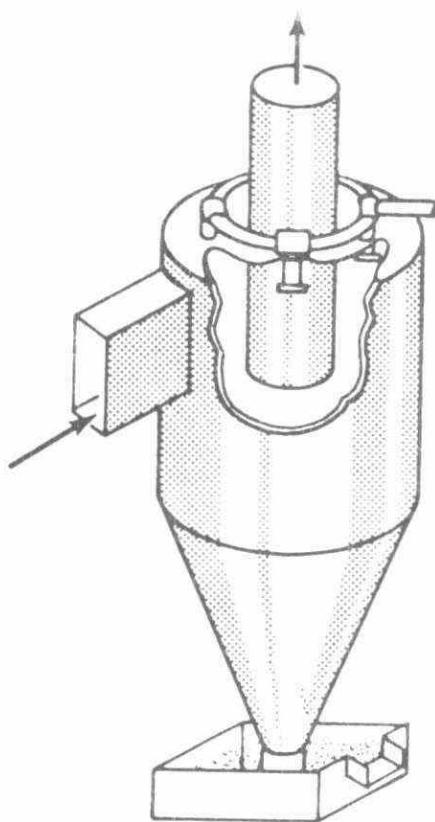
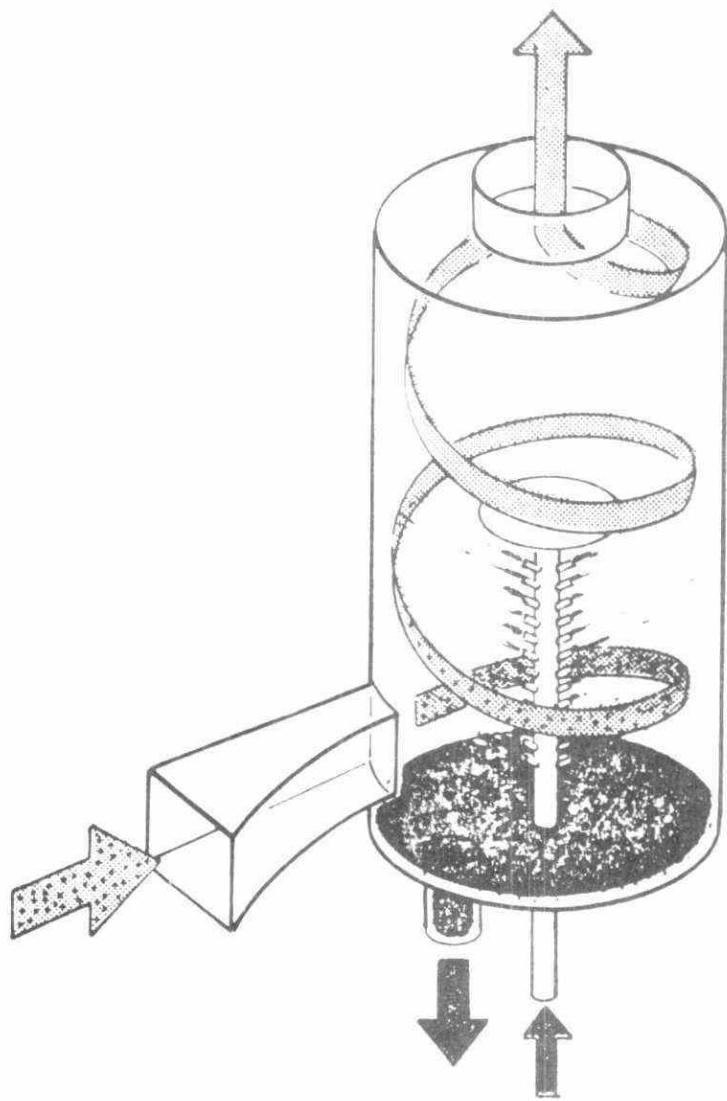


Figure 21-8
Conventional cyclone converted to a scrubber

Figure 21-9 shows a standard type of cyclone scrubber. The gas enters tangentially at the bottom of the scrubber and pursues a spiral path upwards.

Liquid spray is introduced into the rotating gas from an axially located manifold in the lower part of the unit. The atomized fine-spray droplets



Pease-Anthonay scrubber

Figure 21-9

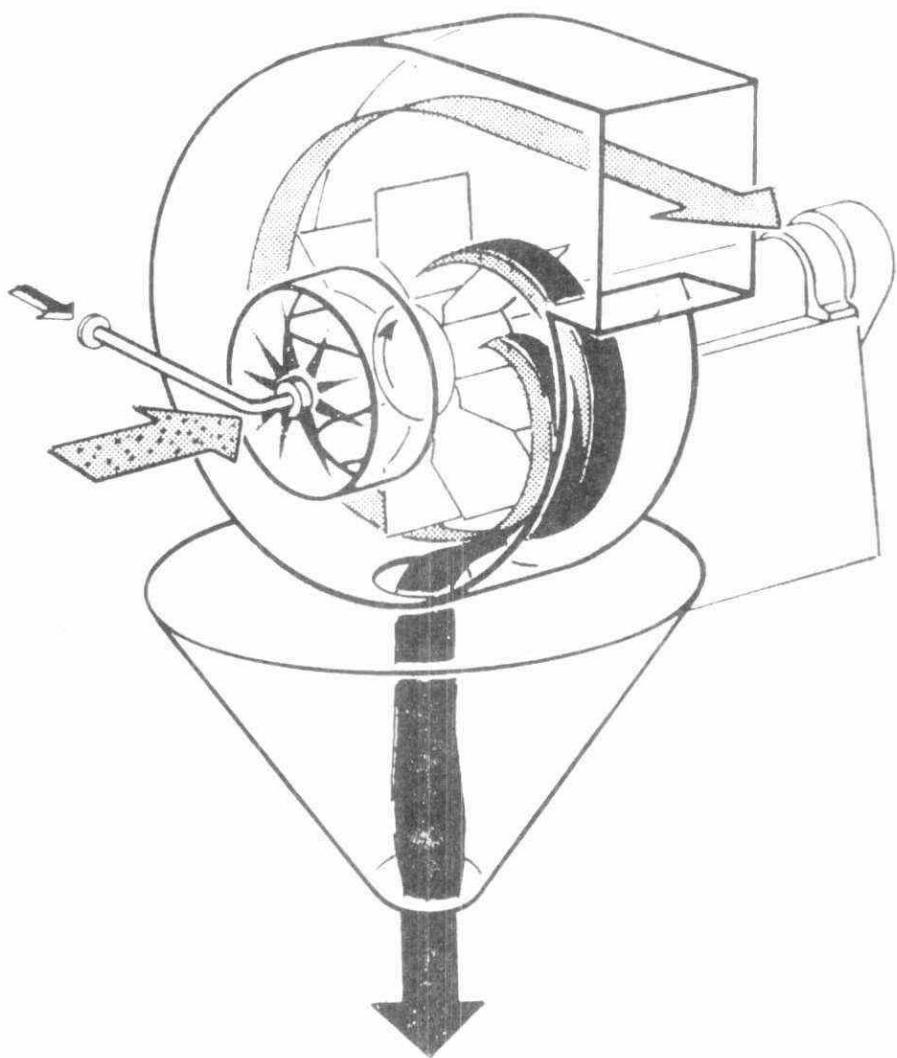
are caught in the rotating gas stream, and are, by centrifugal force, swept across to the walls of the cylinder, colliding with, absorbing and collecting the dust or fume particles. The scrubbing liquid and particles run down the walls and out of the bottom of the unit, the clean gas leaves through the top.

A spray of water, as is shown in Figure 21-10, added to the inlet of a mechanical, centrifugal collector, increases its collection efficiency. The mechanism is mainly one of impingement of dust particles on the rotating blades. The spray formed keeps the blades wet and flushes away the collected dust.

The diagram of Figure 21-11, indicates a venturi scrubber in partial section and an assembly of scrubber and separator. In this device, the gases pass through a venturi tube to which low or high pressure water is added at the throat. Gas velocities at the throat are from 15,000 to 20,000 ft/min. Recirculation of water is feasible. The predominant mechanism is believed to be impaction. In spite of the relatively short contact time, the extreme turbulence in the venturi promotes very intimate contact. The wetted particles and droplets are collected in a cyclone spray separator. Water rates are about 3 g.p.m. per 1000 cfm gas. Very high collection efficiencies have been achieved for very fine dusts.

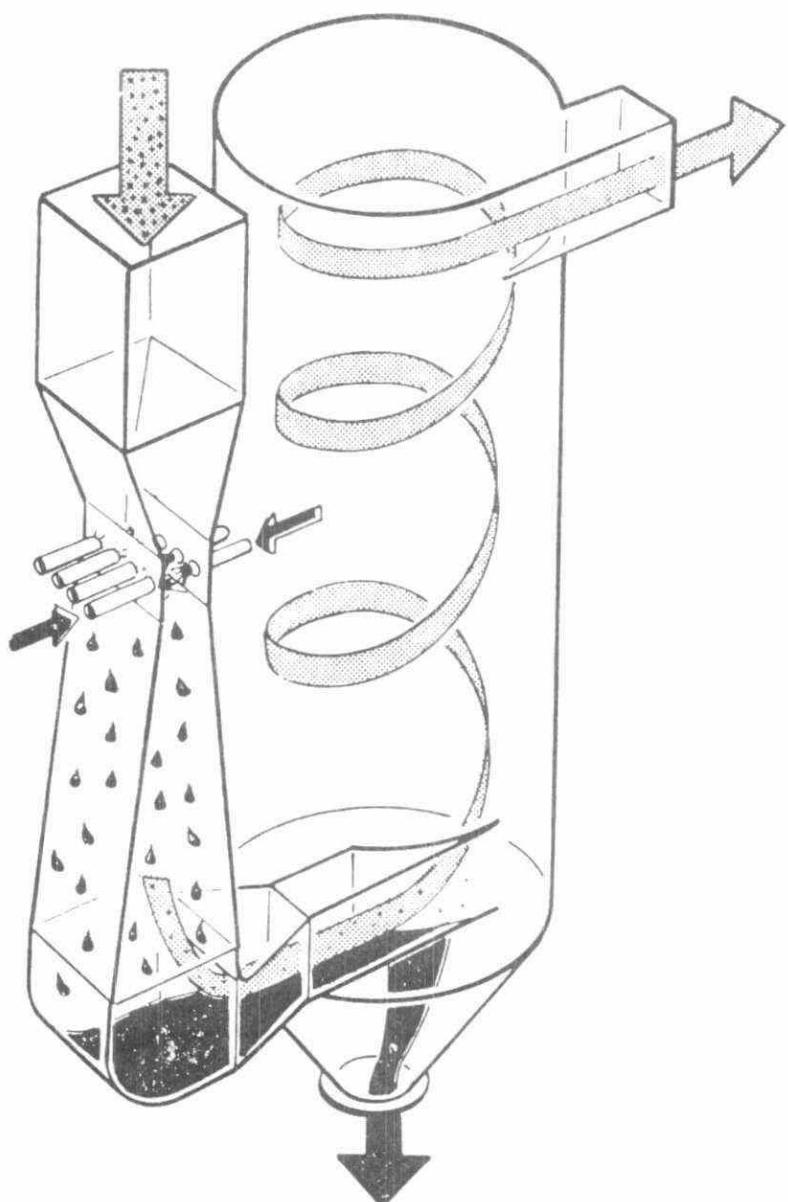
In a tower such as is illustrated in Figure 21-12, the contaminant-laden stream is passed through a bed of granular or fibrous collection material and a liquid is passed over the collecting surface to keep it clean and prevent re-entrainment of deposited particles.

Other scrubbers are illustrated in Figures 21-13 to 16.



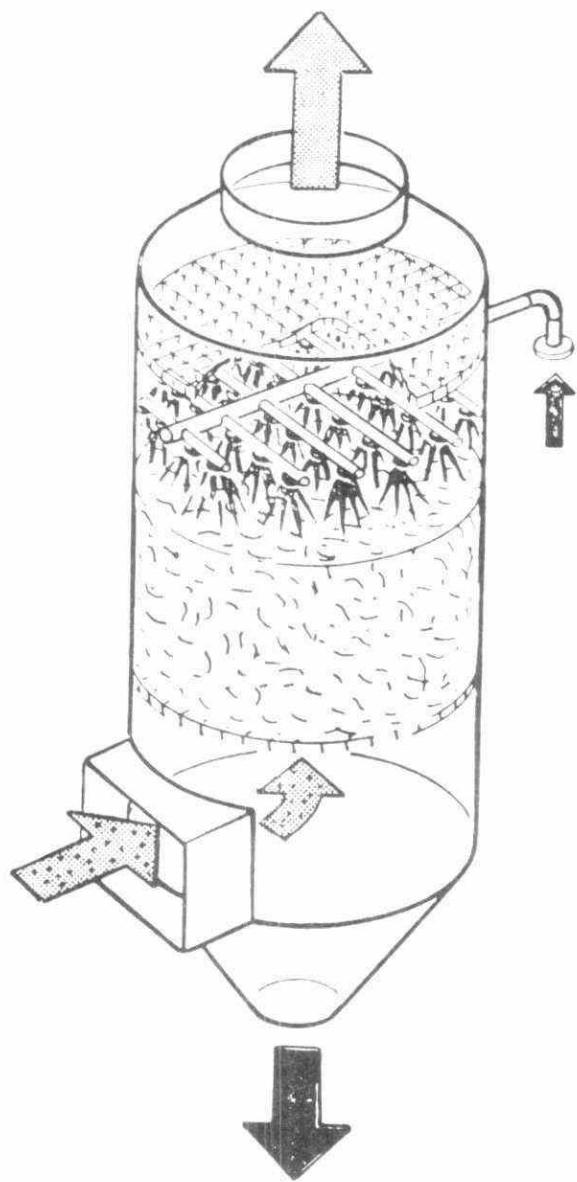
Wet dynamic collector

Figure 21-10



High-pressure venturi

Figure 21-11



Packed tower

Figure 21-12

Wet-type collectors

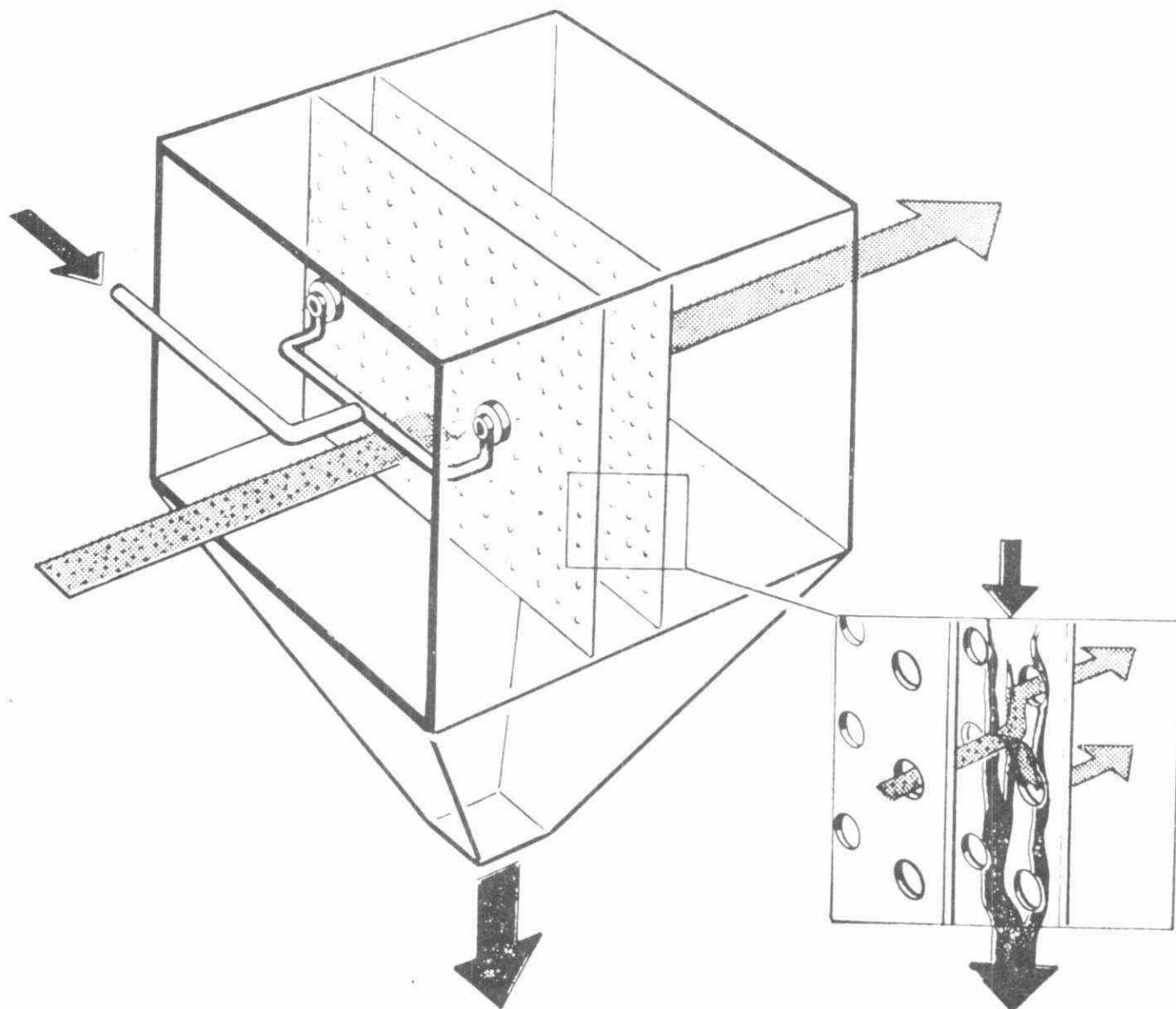


Figure 21-13
Impingement scrubber

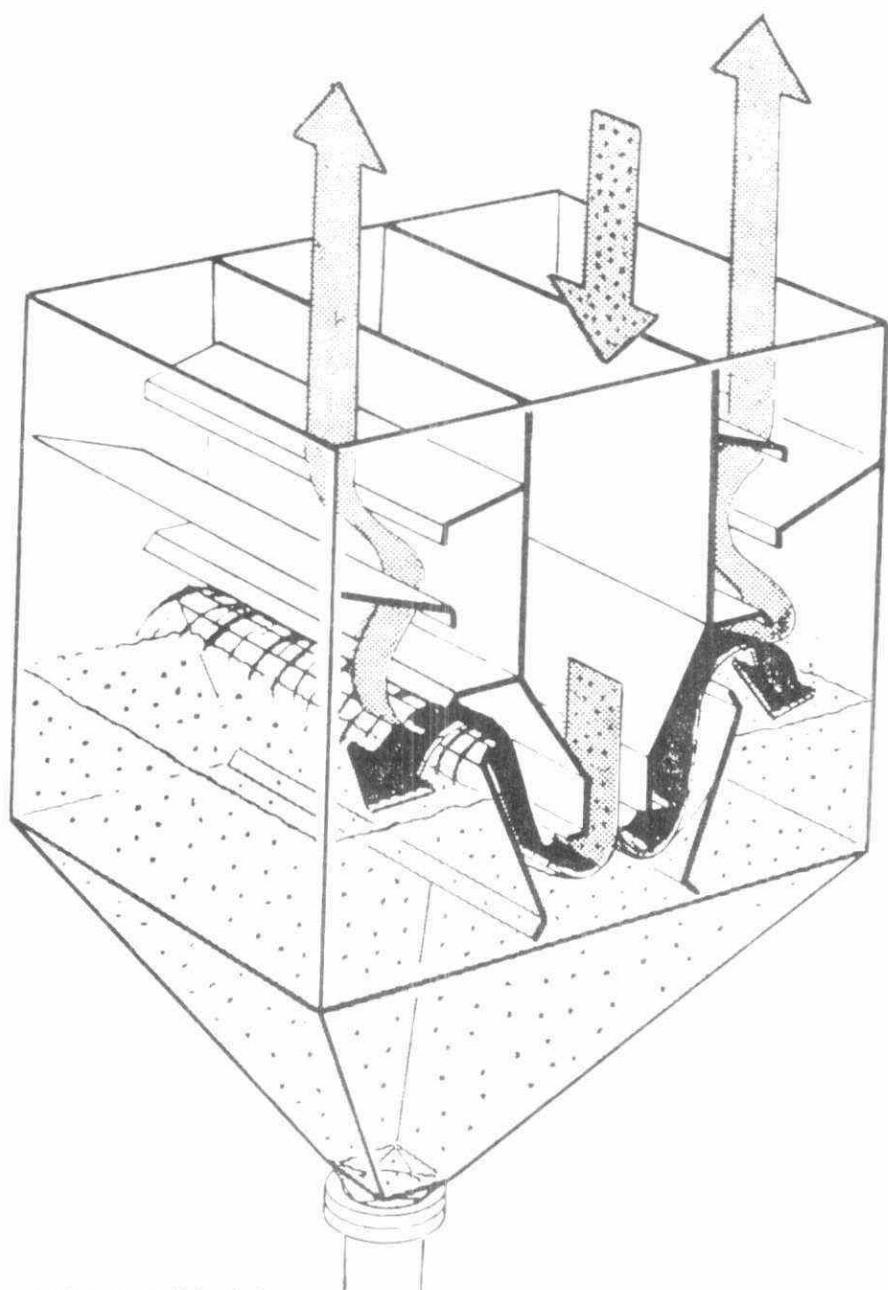
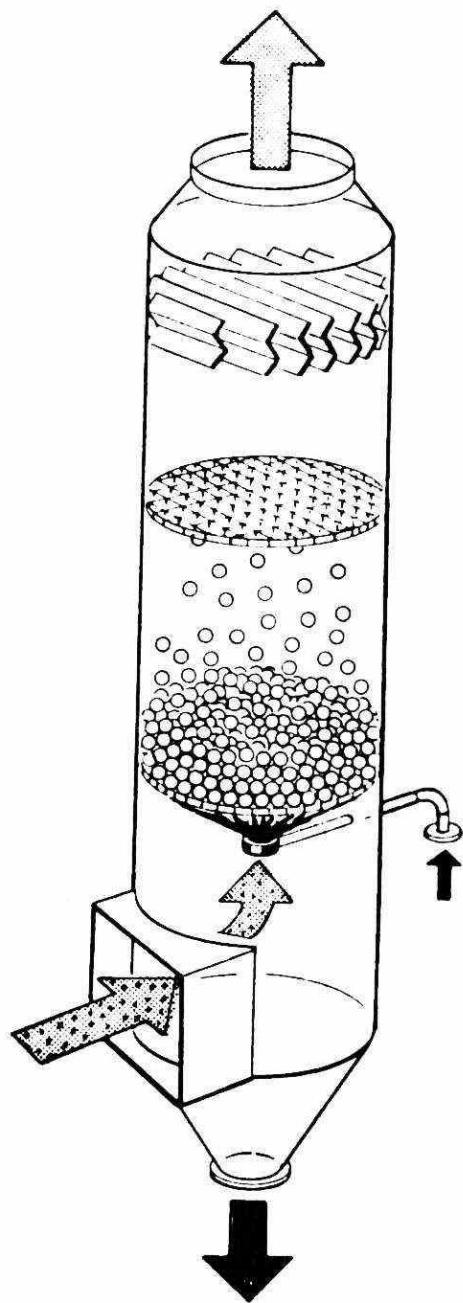


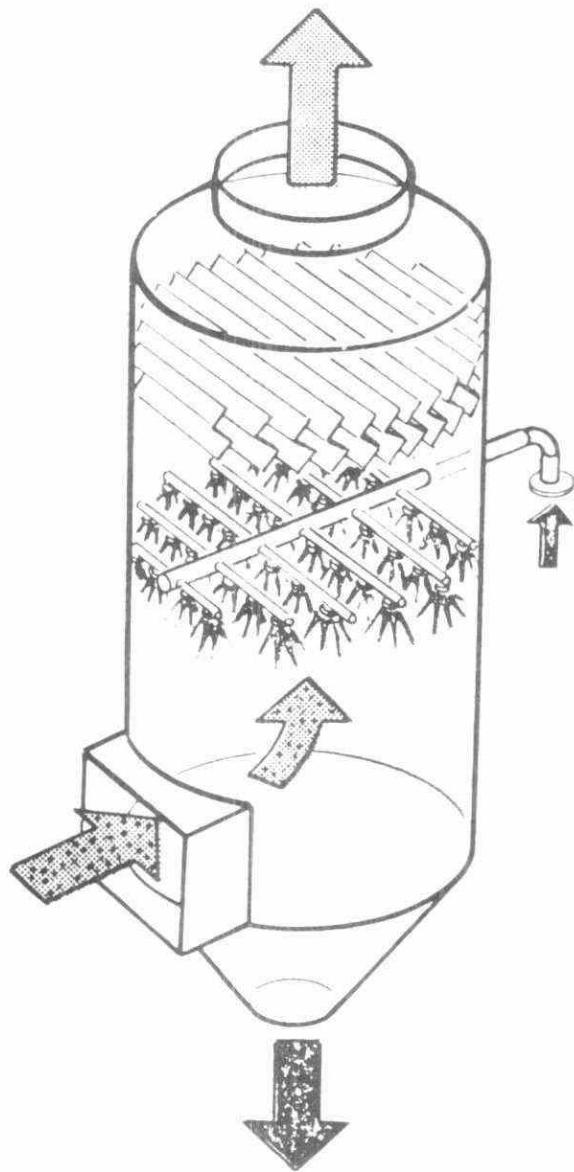
Figure 21-14

Medium-pressure scrubber.
SF type LMV



**Ball scrubber
SF type F**

Figure 21-15



Nozzle scrubber

Figure 21-16

21.15

(vi) Bag Filters are preferred over scrubbers for the collection of dusts and fumes. The positive collection mechanism of the baghouse ensures virtually complete collection of almost any dust or fume. If mists or hygroscopic particles are present in the effluent, a baghouse cannot be used. A typical baghouse is illustrated in Figure 21-17.

In this system the dust is separated from the air by means of a fabric filter. The fabric is usually made into bags of tubular or envelope shape. The filter fabrics are usually woven with relatively large open spaces, sometimes 100 microns or larger. Since collection efficiencies for dust particles of 1 micron or less may exceed 90%, the filtering process obviously cannot be simple sieving. Small particles are initially captured and retained on the fibres of the cloth by means of interception, impingement, diffusion, gravitational settling, and electrostatic attraction. Once a mat or cake of dust is accumulated, further collection is accomplished by sieving as well as by the previously mentioned mechanisms. Periodically, the accumulated dust is removed by shaking. Some residual dust remains and serves as an aid to further filtering. Other methods of cleaning fabric collectors are illustrated in Figures 21-18 to 20.

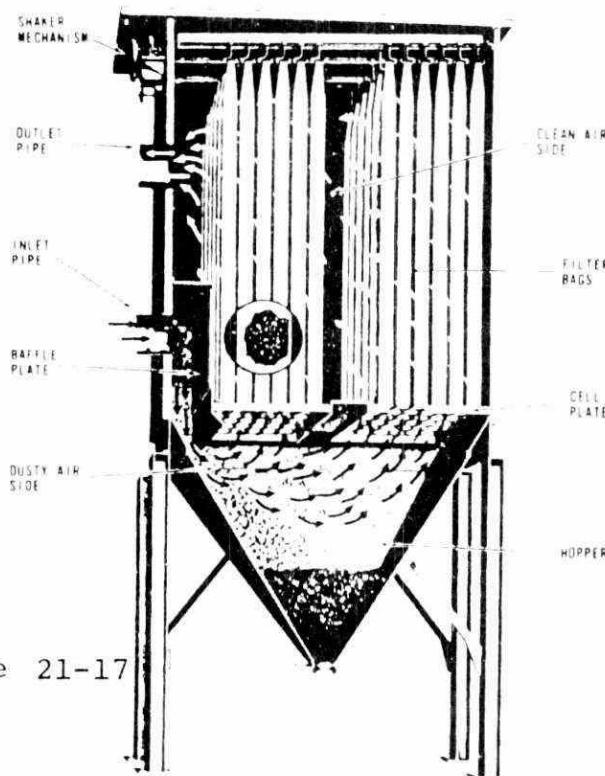
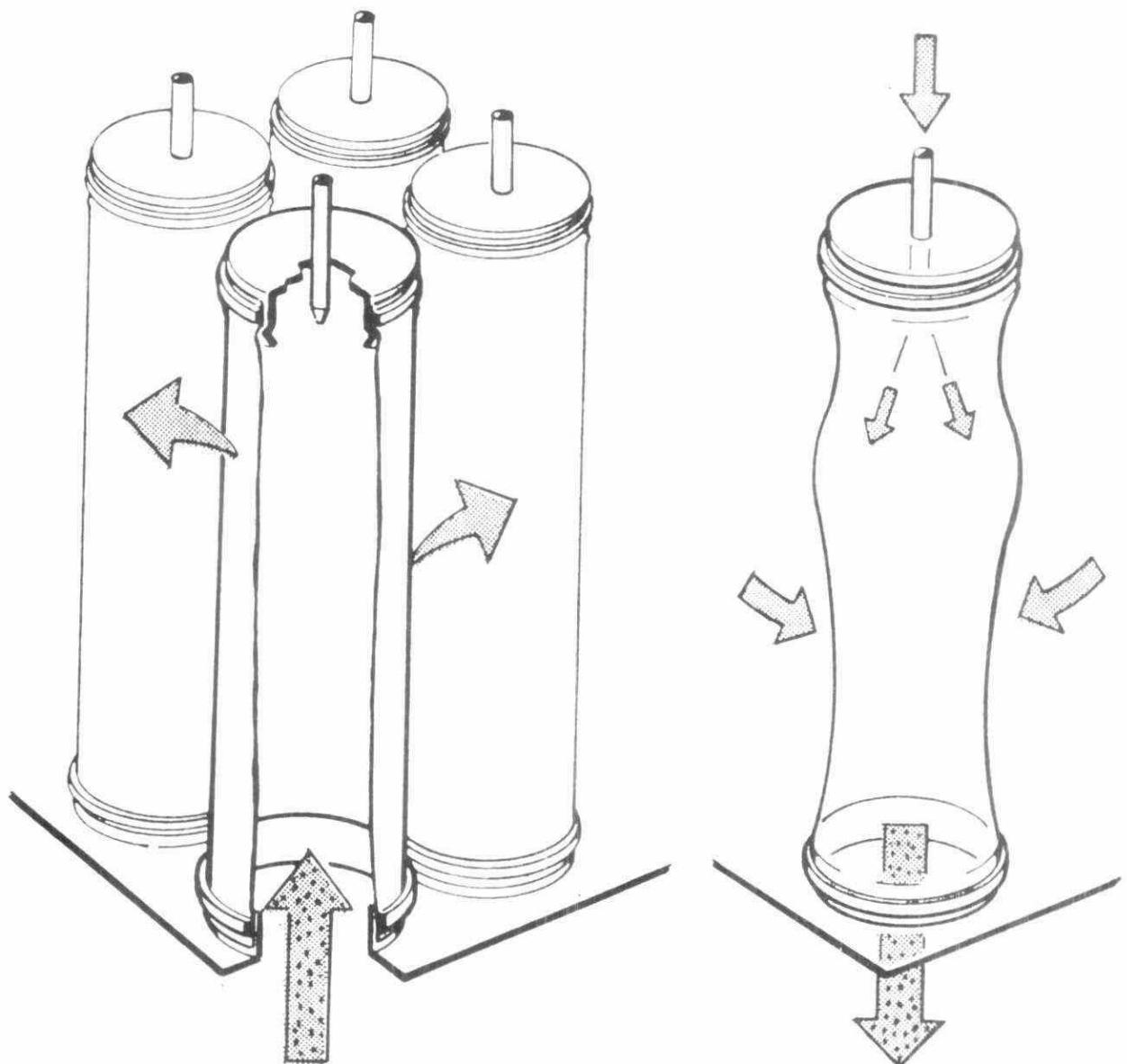


Figure 21-17



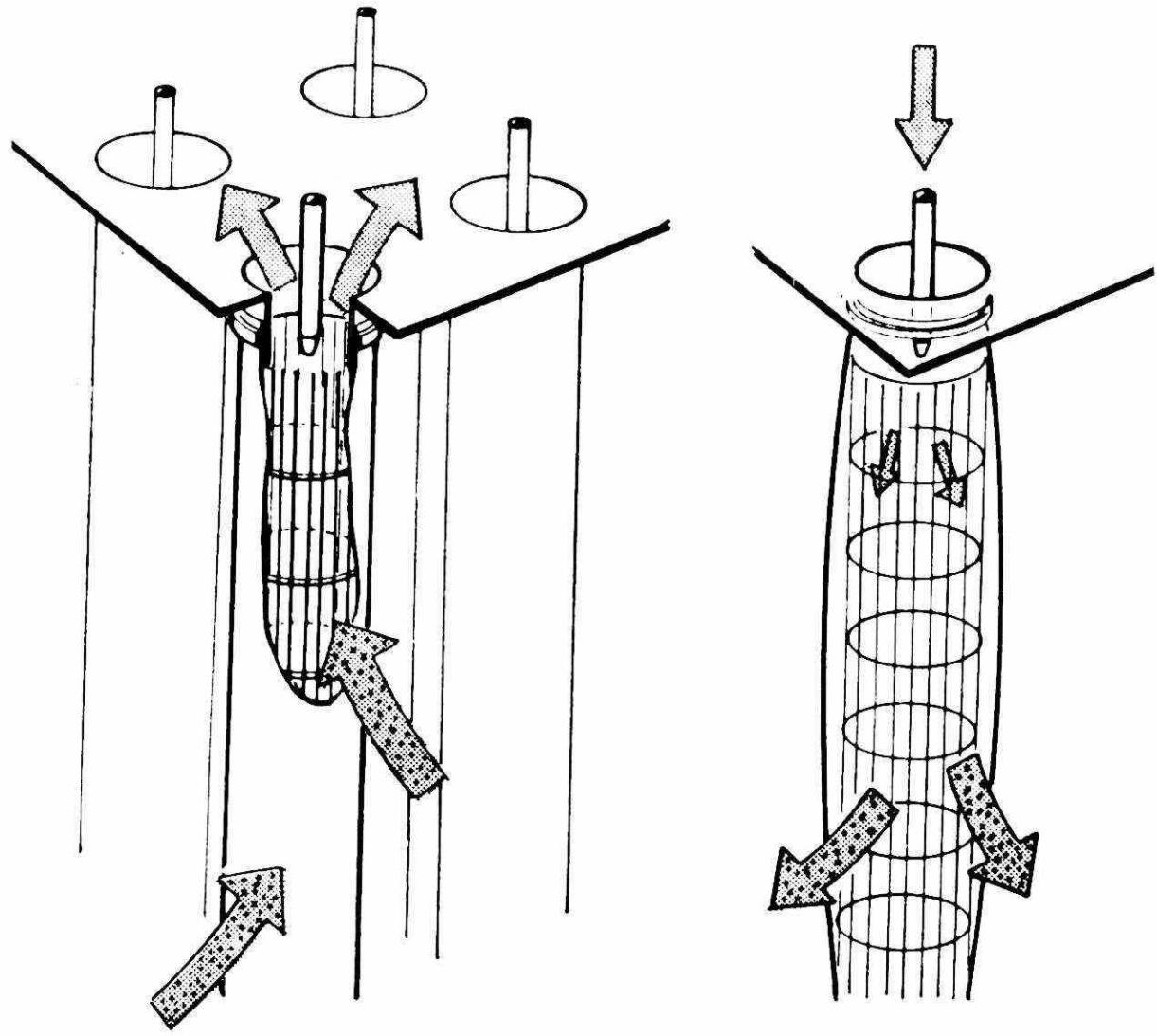
Normal operation

Air bubble cleaning

Fabric collector with air bubble cleaning

FIGURE 21-18

Fabric collectors

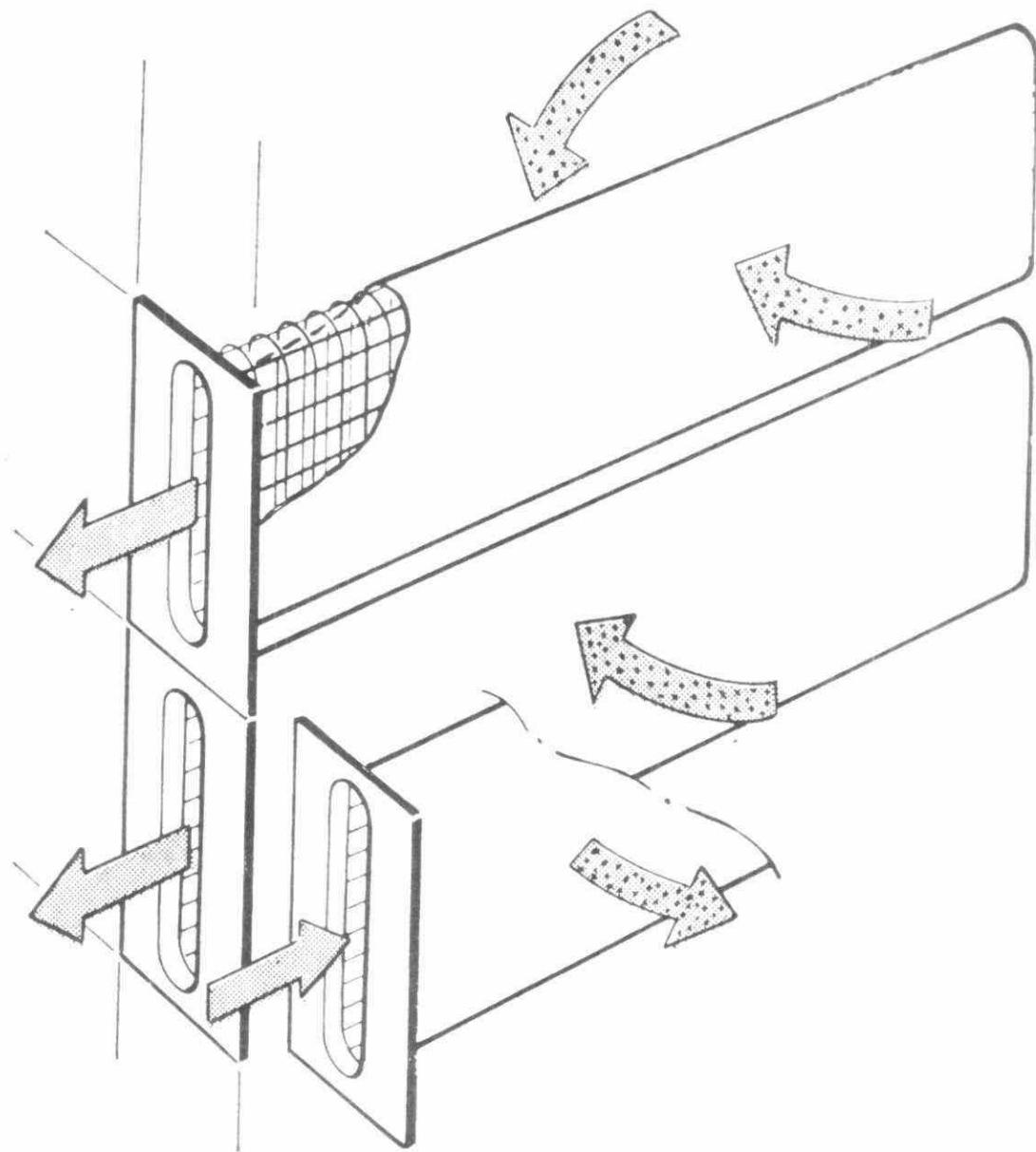


Normal operation

Reverse air cleaning

High-ratio collector

FIGURE 21-19

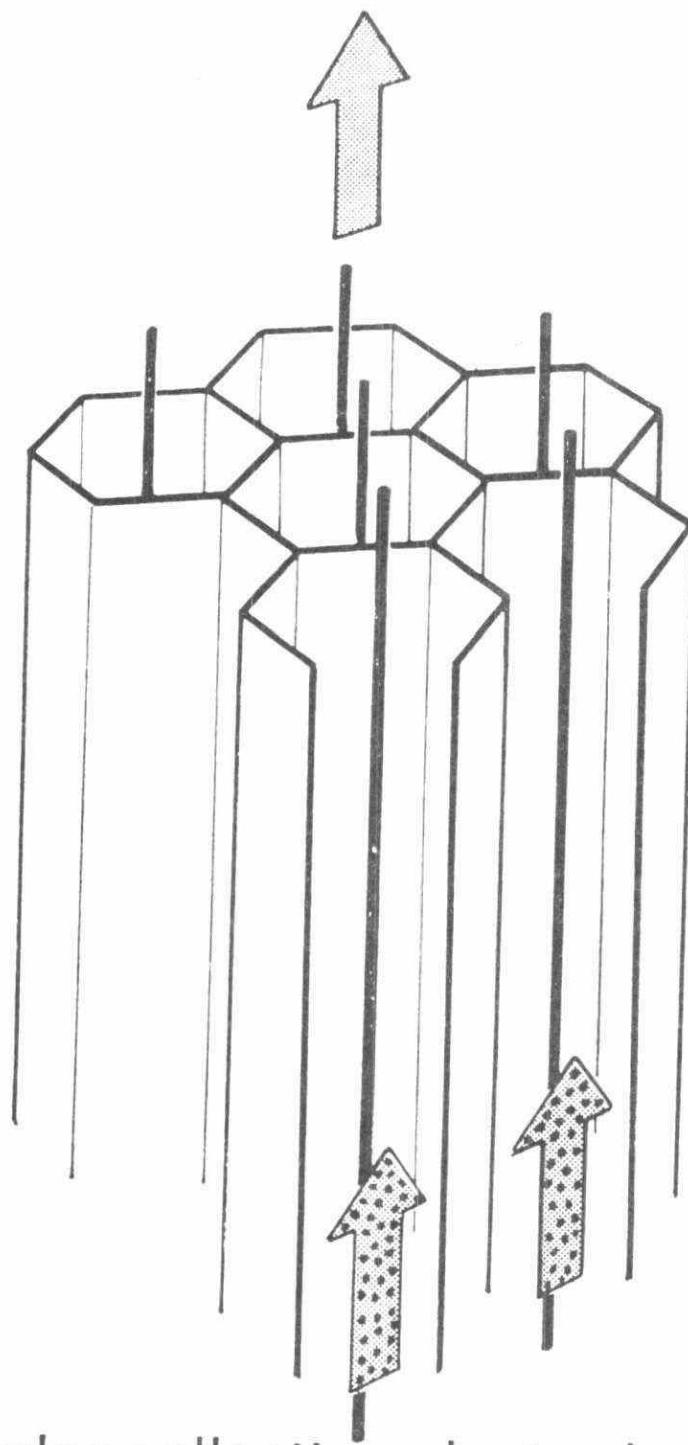


Normal operation

Cleaning

Screen or envelope type collector

FIGURE 21-20



Tubular collecting electrodes

Figure 21-21

Electrostatic precipitators

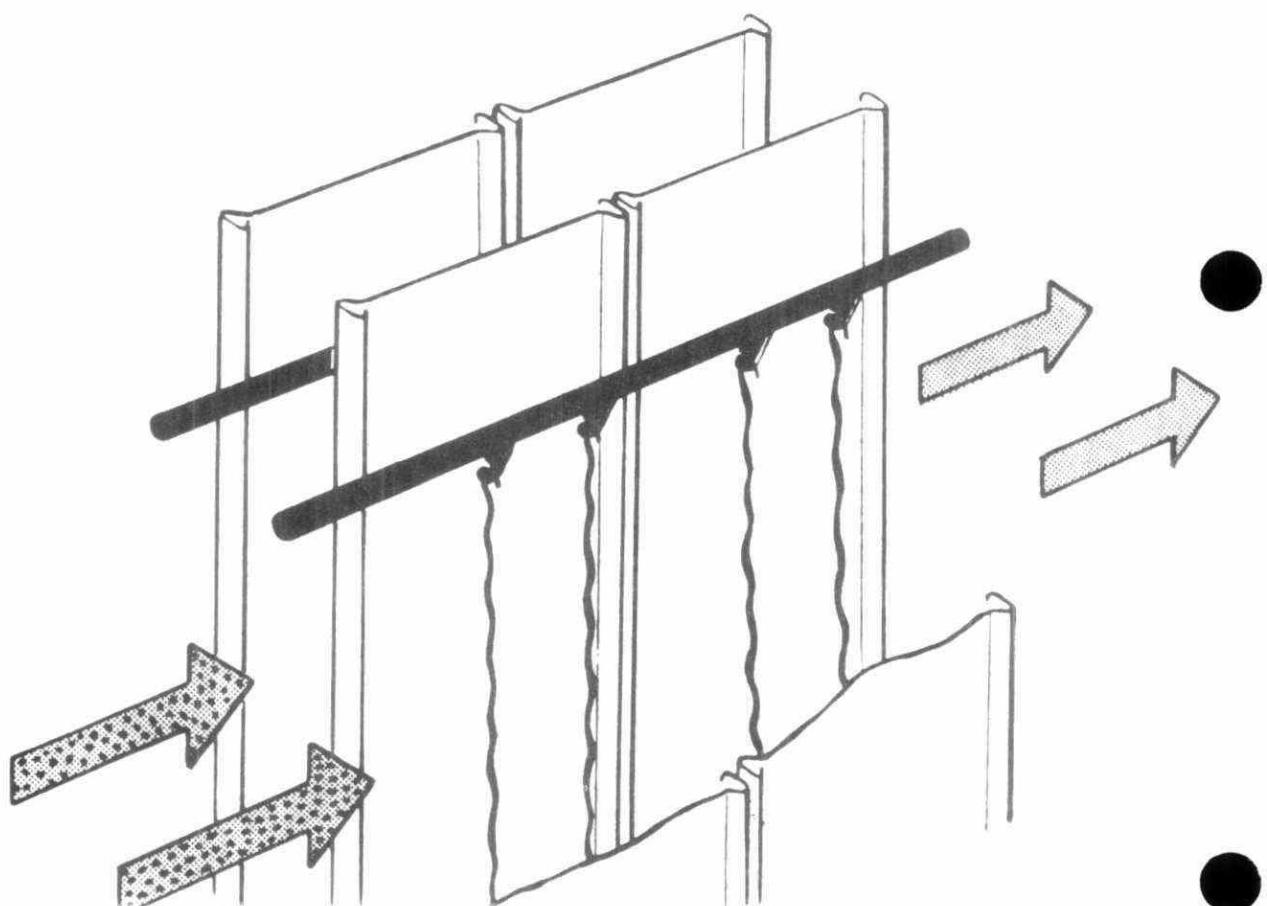
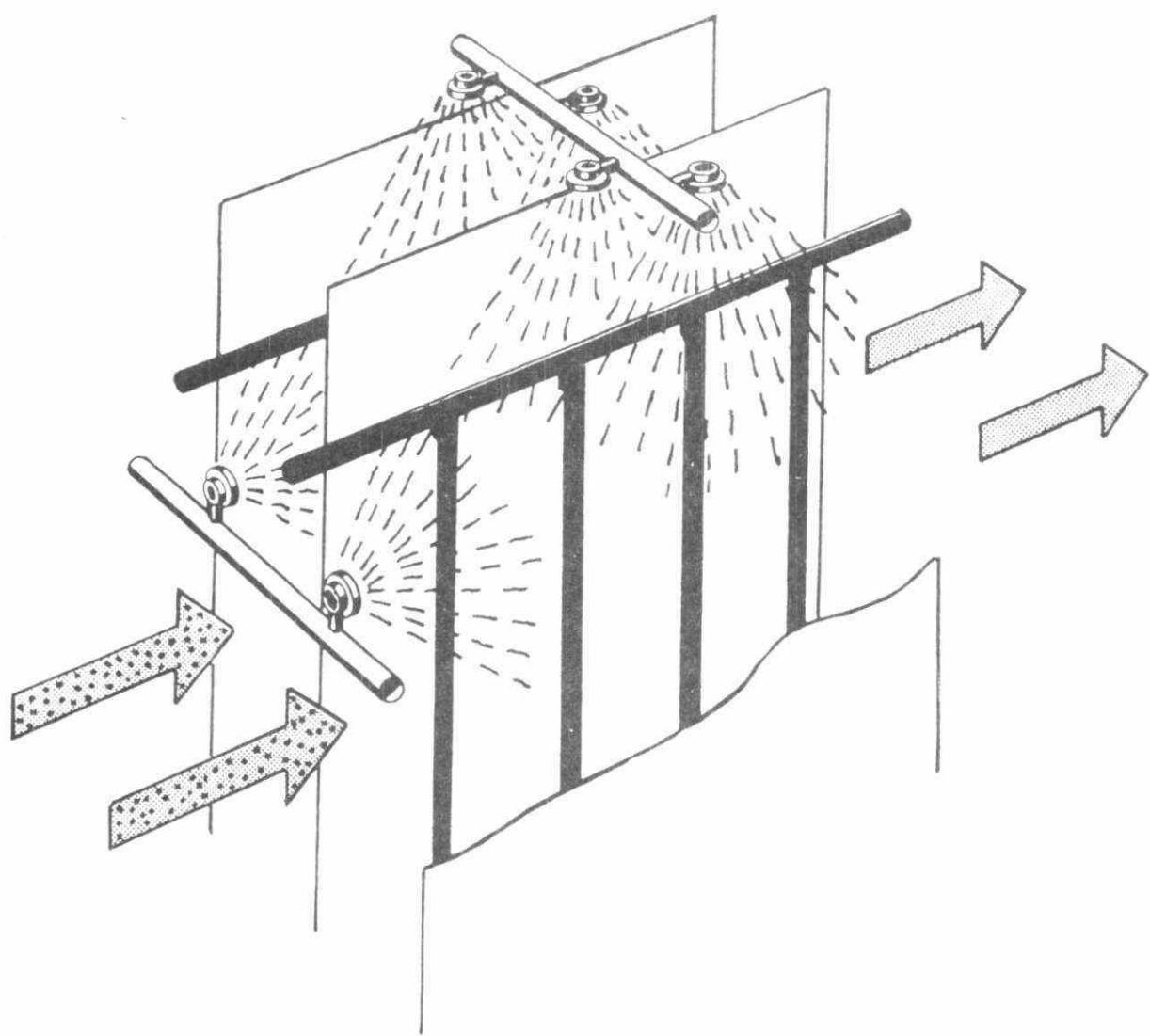


Figure 21-22



Flat collecting electrodes. Wet precipitator to SF design

Figure 21-23

(vii) Electrostatic precipitators are devices in which an

electrostatic field is used for the removal of solid or liquid particles from a gas. The dust-laden gas in such a device flows over high voltage electrode wires between collector plates as is shown by the simplified diagrams of Figures 21-21 to 23

A theoretical analysis of precipitator mechanism and performance involves two fundamental processes: particle charging and particle migration. This mechanism is further illustrated by the diagram of Figure 21-24, which gives a schematic representation of a two-stage precipitator principle.

Basically, electrical precipitation is accomplished by passing the dust-laden carrier gas between two electrodes across which a unidirectional, high voltage potential is impressed. The discharge electrode has a radius much smaller than the second. Due to the differential in radius of curvature, and to the high voltage potential impressed across the

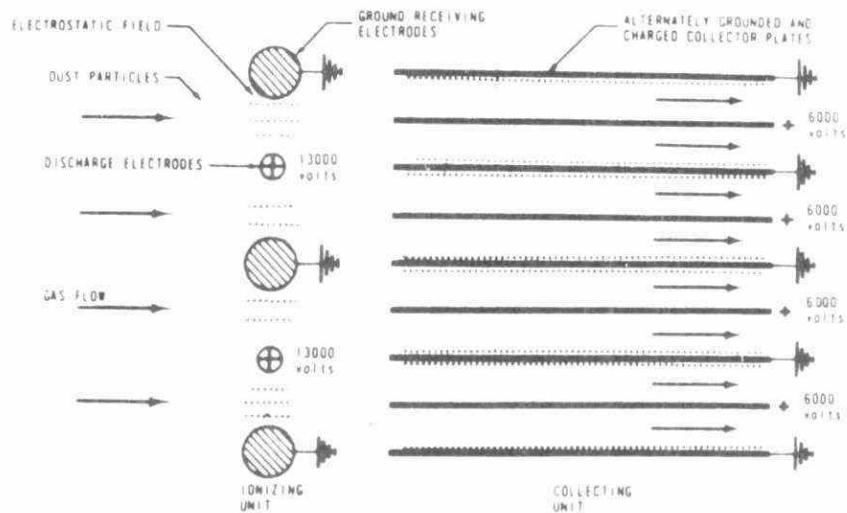


Figure 21-24

Two-stage precipitator

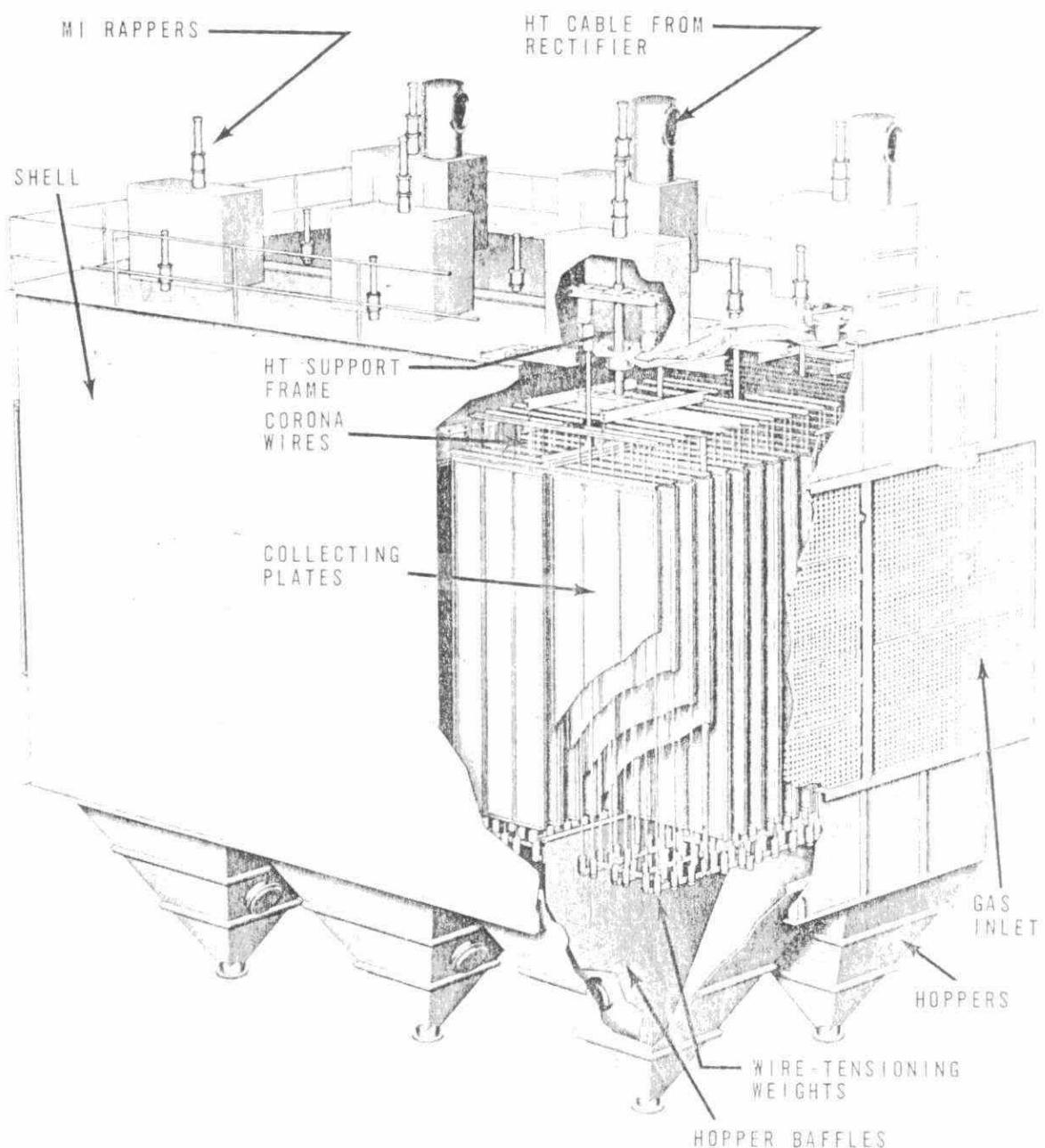
electrode, a corona discharge is established and a powerful ionizing field is formed. The particles in the carrier gas as they pass through this field become charged, and migrate under the action of the powerful electrical field existing between the electrodes to the oppositely charged collecting electrode. The particles, once deposited on the collecting electrode, lose their charge and are removed mechanically by rapping, vibration or washing to a hopper below.

The basic components of an electrostatic precipitator illustrated in Figure 21-25, include the following: outer shell or housing, support frame, hoppers, cable from rectifier, corona wires, wire-tensioning weight, collecting plates and rappers.

Although the horizontal-flow plate type is the most common, precipitators are also built in vertical-flow plate types. There are also "pipe-type" precipitators in which the gas moves up in a parallel flow through dozens or hundreds of vertical pipes, each provided with a high-voltage discharge wire along its axis. The pipes may be rapped to dislodge dry dust, or they may be flushed with water, in which case the dust collects as a slurry at the bottom. In precipitators made to collect sulphuric acid mist, the pipes are covered with sheet lead and the precipitated acid runs down the pipe walls without rapping or flushing.

2. (b) Equipment for Control of Gaseous Contaminants

21.17 Control equipment for gaseous contaminants and odours employ different techniques compared to those used for aerosols. The control of noxious gases and odours is far from standardized, mainly because of the widely varying chemical and physical properties, and encountered concentrations.



Basic structure of a typical precipitator (Western Precipitation, Division of Joy Manufacturing Co., Los Angeles, Calif.).

FIGURE 21-25

Control equipment which is used for gases and vapours include: (i) incineration; (ii) absorption; (iii) adsorption; and (iv) condensation units.

21.18

(i) Incineration or Combustion. In some cases, the specific contaminant prevents efficient collection, but can more easily be converted into an innocuous substance and dispersed. This is feasible where the pollutant gas or odorous components are oxydizable. Normally, organic contaminants may be destroyed by exposure to temperatures in excess of 650°C by the use of direct-fired afterburners.

A schematic diagram of a typical afterburner is shown in Figure 21-26.

Under certain conditions, the use of catalysts may lower the required temperatures for oxidation. Catalytic after-burners have found their greatest use in the control of solvent and organic vapour emissions exhausted from industrial ovens. These emissions are created in metal-decorating and metal-coating ovens, fabric-backing and fabric-coating ovens and ovens for the baking of the binder in the production of rock-wool batts.

A typical industrial oven using a catalytic after-burner is shown in Figure 21-27. In this operation the contaminated gases are delivered to the after-burner by the exhaust fan. The gases pass into the preheat zone where they are heated to the temperature required to support catalytic combustion. This temperature varies with the nature and composition of the contaminants to be burned, generally being about 340° to 540°C. Some burning of contaminants usually occurs in the preheating zone. The preheated gases then flow through the catalyst bed where the remaining combustible contaminants are burned by catalysis.

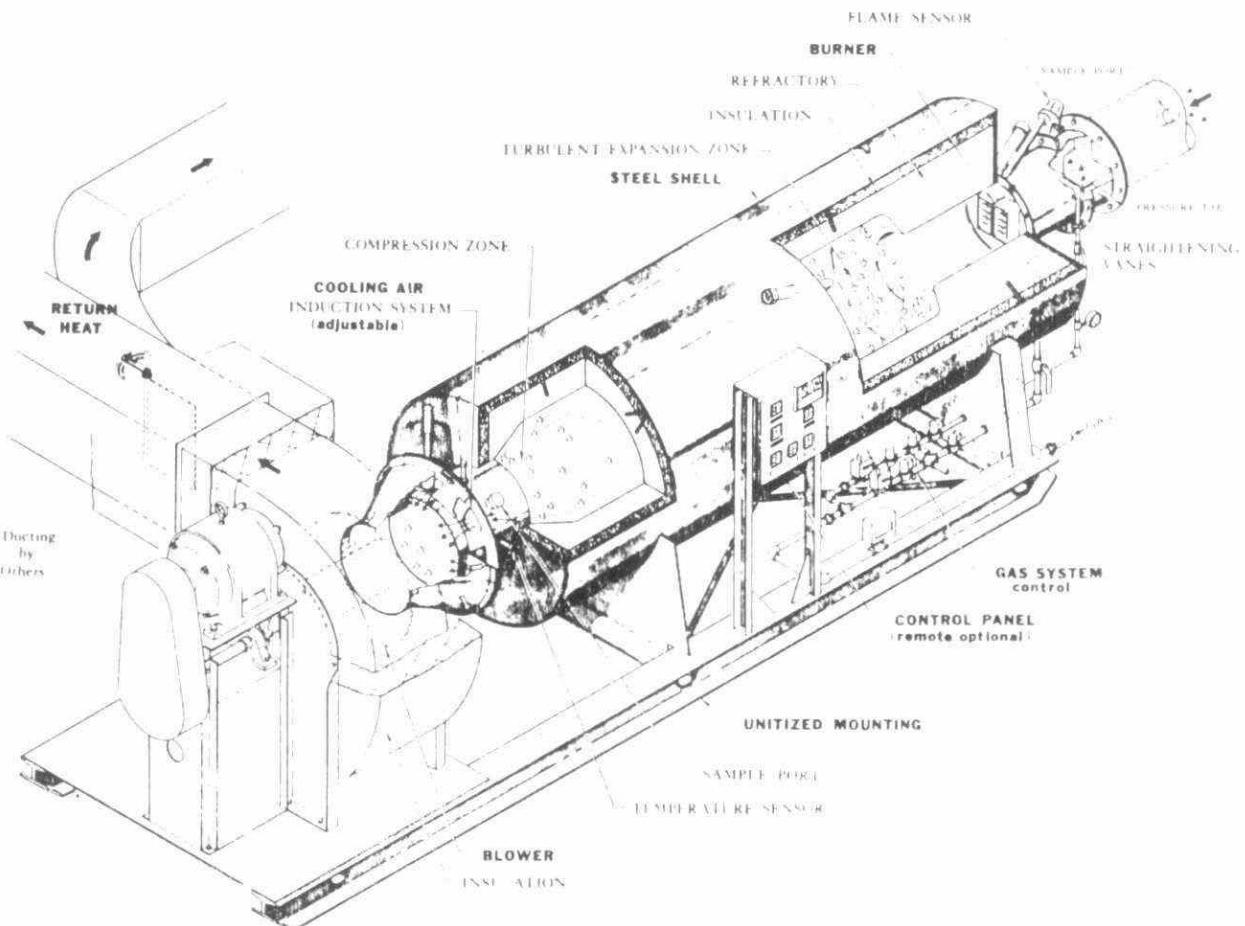


Figure 21-26

Sectional view of a direct-flame afterburner (Gas Processors, Inc., Brea, Calif.)

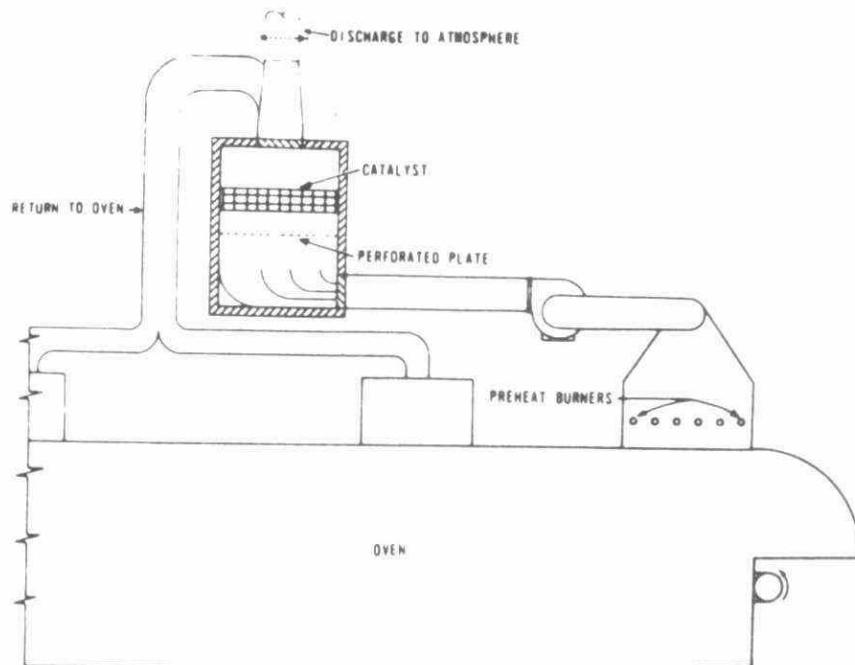


Figure 21-27
Typical catalytic afterburner

21.19

(ii) Gas absorption is the mechanism whereby one or more constituents are removed from a gas stream by dissolving them in a selective liquid solvent.

From an air pollution standpoint, absorption is useful as a method of reducing or eliminating the discharge of air contaminants to the atmosphere. The gaseous air contaminants most commonly controlled by absorption include sulphur dioxide, hydrogen sulphide, hydrogen chloride, chlorine, ammonia, oxides of nitrogen and light hydrocarbons.

As far as equipment is concerned, packed towers are used for this purpose.

21.20

(iii) Gas adsorption is the name for the phenomena in which molecules of a fluid contact and adhere to the surface of a solid. By this process, gases, liquids, or solids, even at very low concentrations, can be selectively captured or removed from air-streams with materials known as adsorbents. The material adsorbed is called the adsorbate.

The operation of adsorption involves three steps. First, the adsorbent is contacted with the fluid, and a separation by adsorption results. Second, the unadsorbed portion of the fluid is separated from the adsorbent. In the case of gases, this operation is completed on passage through the adsorbent bed. Third, the adsorbate is removed from the adsorbent which thereby regenerates the adsorbent.

There is a variety of solids which possess adsorptive properties. The one that is most suitable for the removal of organic vapours is activated carbon.

Figure 21-28 illustrates the method of operation of an adsorber having four fixed beds of activated carbon.

The gas stream containing the vapour enters the side of the enclosure, flows through the carbon beds and exits at the opposite side. Superheated steam, for regeneration of the adsorbent, is admitted at right angles to the carbon bed.

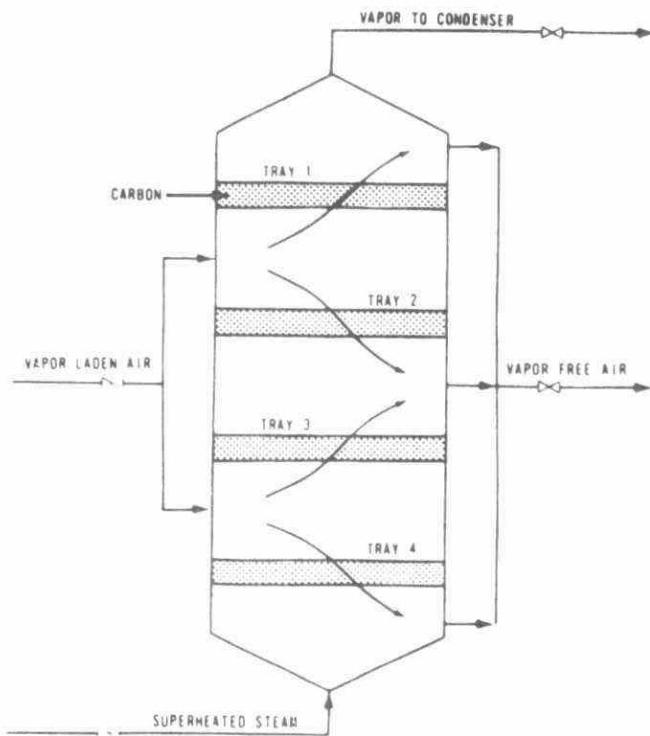


Figure 21-28
Typical fixed-bed adsorber

There are many variations of this type of adsorber, including continuous adsorbers.

21.21

(iv) Condensation. In specific instances, control of vapour-type discharges can best be accompanied by condensation. Other applications of air pollution control may require a condenser to be an integral part of the equipment. In these cases, a condenser reduces the load on a more expensive control device or removes vapour components that may affect the operation or cause corrosion of the main control element.

Vapours may be condensed by either surface or contact condensers.

CONCLUSION

21.22 The preceding sections outlined the various methods available today for the reduction of contaminant discharge. The hardware is available in a wide variety of designs based on the various principles described. There is a wide latitude in collection efficiency, initial cost, operating and maintenance costs, space, arrangement, materials of construction and operational reliability.

In selecting control equipment for a specific job, it is necessary to consider many factors such as physical and chemical properties of the contaminants, carrier gas characteristics, process and operational factors.

21.23 The advantages and disadvantages of scrubbers, bag filters, and electrostatic precipitators are as follows:

21.24 Low Energy Scrubbers

Advantages

Low initial cost

Low power costs

Space requirements less than most other types of control equipment

Disadvantages

Usually limited to particulate over 1 - 2 microns

Handling and disposal of the slurry may present problems

Abrasion and corrosion

Mist carry over (Vapour Plume)

Good distribution of gas, scrubber fluid and particulate to avoid streaming.

High Energy Scrubbers

Advantages

Comparatively low initial cost

Low space requirements

High efficiency

Disadvantages

High power requirements
May present noise problems
Abrasion and corrosion
Mist carry over (Vapour Plume)
Slurry Handling and disposal may be difficult

21.26 Bag Filters

Advantages

Extremely high efficiencies even on very fine particles
Can accept reasonably wide range of inlet dust concentrations.

Disadvantages

Difficulty in handling saturated gases.
Gas temperature limited by characteristics of filter media.
Initial costs can be high when high efficiency and availability are required on fine dusts.
Filter media replacement costs may be high.

21.27 Electrostatic Precipitators

Advantages

Extremely high efficiencies even on very fine particles.
Low pressure drop.
Can handle wide range of gas temperatures.

Disadvantages

High initial cost.
Design dependent on electrical characteristics of dust.
On line maintenance can be hazardous.

G L O S S A R Y

ABSOLUTE THERMODYNAMIC TEMPERATURE: Temperature measured on the Kelvin scale of temperature. The magnitude of the degree absolute is the same as on the Centigrade scale, but to convert temperatures on the Centigrade scale to degrees absolute (A° or $^{\circ}K$) add 273.

ABSORBER: A device utilized to extract selectively one or more elements of a gas stream from others by absorption in a liquid medium. Usually the process is performed in cylindrical towers packed with an inert material thus providing a large surface area for intimate contact between the rising gas and the falling liquid. (The process may also be carried out in a tower containing perforated trays in which the rising gas bubbles through the layer of liquid on the trays.)

ABSORPTION: A process in which one or more constituents are removed from a gas stream by dissolving them in a selective liquid solvent. This may or may not involve a chemical change.

ACCELERATOR (chem.): A substance which increases the rate of a chemical reaction (i.e. a catalyst), particularly in the manufacture of vulcanized rubber.

ACCUMULATOR: A vessel for the temporary storage of a gas or liquid; usually used for collecting sufficient material for a continuous charge to a refining process.

ACID: Substance which liberates hydrogen ions in solution; substance which contains hydrogen which may be replaced by a metal to form a salt; substance having a tendency to lose protons. Many acids are corrosive, have a sour taste, and turn litmus red.

ACID SLUDGE: The residue left after treating petroleum oil with sulphuric acid for the removal of impurities. It is a black, viscous substance containing the spent acid and impurities which have been separated from the oil.

ACID SMUTS: Acid smuts are solid and liquid conglomerates formed by the condensation of water vapour and sulphur trioxide on cold metal surfaces. They are frequently caused by combustion flue gases coming in contact with a surface whose temperature is below the dew point of the flue gas. They contain metallic sulphate and carbonaceous particles and are approximately one-quarter inch (6,350 microns) in size.

ACID TREATMENT: An oil-refining process in which unfinished petroleum products, such as gasoline, kerosene, diesel fuel, and lubricating stocks, are contacted with sulphuric acid to improve colour, odour, and other properties.

ACIDULATE: To make acid, especially slightly acid; to treat with acid.

ACOUSTICS: The study of sound.

ACTIVATED CARBON: active charcoal. Carbon, especially charcoal, which has been treated to remove hydrocarbons and to increase its powers of adsorption. Used in many industrial processes for recovering valuable materials out of gaseous mixtures; as a deodorant; and in gas masks.

ADDITION REACTION: Direct chemical combination of two or more substances to form a single product, such as the union of ethylene and chlorine to form ethylene dichloride:



ADIABATIC LAPSE RATE: The rate at which a given mass of air lifted adiabatically (without loss or gain of heat) cools due to the decrease of pressure with increasing height, $5.4^{\circ}\text{F}/1000 \text{ ft.}$ ($9.7^{\circ}\text{C}/\text{km}$).

ADIABATIC PROCESS: A thermodynamic change of state of a system in which there is no transfer of heat or mass across the boundaries of the system.

ADIABATIC TEMPERATURE: (Combustion) The theoretical temperature that would be attained by products of combustion provided the entire chemical energy of the fuel, the sensible heat content of the fuel, and combustion air above the ambient temperature were transferred to the products of combustion. This assumes (1) that combustion is complete, (2) that there is no heat loss, (3) that there is no disassociation of the gaseous compounds formed, and (4) that inert gases play no part in the reaction.

ADSORBATE: The substance which is adsorbed on a surface. See adsorption.

ADSORPTION: A reaction in which one or more constituents (adsorbates) are removed from a gas stream by contacting and adhering to the surface of a solid (adsorbent). Periodically the adsorbent must be regenerated to remove the adsorbate.

AEROBIC: In the presence of free oxygen.

AEROSOL: A colloidal system in which particles of solid or liquid are suspended in a gas. There is no clear-cut upper limit to the particle size of the dispersed phase in an aerosol, but as in all other colloidal systems, it is commonly set at 1 micrometre. Haze, most smoke, and some fogs and clouds may be regarded as aerosols.

AFTERCURNER: A device, including an auxiliary fuel burner and a combustion chamber, in which the combustible air contaminants are incinerated.

Direct Flame Afterburner: That type in which the auxiliary burner provides all the necessary heat and flame contact necessary for incineration.

Catalytic Afterburner: That type in which the surface action of catalysts are employed such that incineration occurs at a lower temperature than it would in a direct flame unit. Less auxiliary heat is required with a catalytic afterburner than with a direct flame afterburner.

Recuperative Afterburner: A direct flame unit in which a heat exchanger is utilized to pre-heat the incoming contaminated gases so that less auxiliary fuel is required.

AGGLOMERATION: Groups of fine particles clinging together to form a larger particle.

AIR ATOMIZING OIL BURNER: A burner in which oil is atomized by compressed air which is forced into and through one or more streams of oil thus breaking it into a fine spray.

AIR HEATER OR AIR PREHEATER: Heat transfer apparatus through which combustion air is heated by a medium of higher temperature, such as the products of combustion or steam.

ALKYLATION: In petroleum refining, usually the union of an olefin (ethylene through pentene) with isobutane to yield high-octane, branched-chain paraffinic hydrocarbons. Alkylation may be accomplished by thermal and catalytic reactions. Alkylation of benzene and other aromatics with olefins yields alkyl aromatics.

ALUMINA: Aluminum oxide (Al_2O_3), an intermediate product of the production of aluminum. This oxide also occurs widely in nature as corundum.

AMBIENT AIR: That portion of the atmosphere, external to buildings, to which the general public has access (the surrounding local air).

ANAEROBIC: In the absence of free oxygen.

ANNEALING: Very slow regulated cooling, especially of metals, to relieve strains set up during heating or other treatment.

ANODE: In aluminum production, the positively charged carbon terminal in the reduction cell or pot. Oxygen is attracted to the anode where it combines with carbon plus any impurities, such as sulphur, which may be present. The anode is consumed by this process and must be replaced periodically.

ANTHRACITE COAL: A hard, black, lustrous coal containing a high percentage of fixed carbon and a low percentage of volatile matter. Commonly referred to as "hard coal".

AREA SOURCE: Any small residential, governmental, institutional, commercial, or industrial fuel combustion operations, as well as on-site waste disposal and transportation sources (see point source).

AROMATIC COMPOUNDS (chem.): Organic compounds derived from benzene.

ASH: Incombustible residue left after the complete combustion of any substance. Consists of the non-volatile, inorganic constituents of the substance.

ASH-FREE BASIS: The method of reporting fuel analysis whereby ash is deducted and other constituents are recalculated to total 100 per cent.

ASME: The American Society of Mechanical Engineers.

ASPIRATING BURNER: A burner in which the fuel in a gaseous or finely divided form is burned in suspension. The air of combustion is supplied by drawing it through one or more openings by the lower static pressure created by the velocity of the fuel stream.

ASTM: The American Society for Testing and Materials.

ATMOSPHERE: The normal or standard unit of pressure. The pressure which will support a column of mercury 760 mm. high (29.92 inches) at 0°C., sea-level and latitude 45°. 1 normal atmosphere = 1.0132 bars = 14.72 lb./sq.in. (approx.). Atmospheric pressure fluctuates about this value from day to day.

ATMOSPHERIC PRESSURE: The pressure due to the weight of the atmosphere. Normal atmospheric pressure at sea level is approximately 14.7 p.s.i. or 29.92 inches of mercury.

ATOM: The smallest particle of an element that can exist either alone or in combination with other atoms of the same or of another element.

ATOMIZER: A device by means of which a liquid is reduced to a very fine spray.

AUTOCLAVE: Thick-walled vessel with a tightly fitting lid, in which substances may be heated above 100°C.

AUXILIARY FUEL FIRING EQUIPMENT: Equipment to supply additional heat to incinerators by the combustion of an auxiliary fuel for the purpose of obtaining temperatures sufficiently high: (a) to dry and ignite waste material, (b) to maintain ignition thereof, and (c) to promote complete combustion of combustible solids, vapours and gases.

AVAILABLE HEAT: The quantity of useful heat per unit of fuel available from complete combustion after deducting dry flue gas and water vapour losses.

AVOGADRO'S LAW: Avogadro's hypothesis. Equal volumes of all gases contain equal numbers of molecules under the same conditions of temperature and pressure.

BAG FILTER: A device containing one or more cloth bags for recovering particles from the dust-laden gas which is blown through it.

BAGHOUSE: Structures containing several bag filters (see bag filters).

BAG-TYPE COLLECTOR: A filter wherein the cloth filtering medium is made in the form of cylindrical bags.

BANKING: Burning solid fuels on a grate at rates sufficient to maintain ignition only.

BARK BOILER: A combustion unit designed to burn mainly bark and wood residues, used to produce steam for process or electrical energy.

BAROMETRIC CONDENSER: An inexpensive direct contact condenser used when condensate recovery is not a factor. In this type of condenser, steam rises into a rain of cooling water, and both condensed steam and water flow out of the bottom of the condenser, maintaining a partial vacuum in the condenser.

BASE (chem.): Substance which reacts with an acid to form a salt and water only; substance which has a tendency to accept protons; substance which yields hydroxyl ions if dissolved in water.

BASE STOCK: A sheet, usually produced from unbleached kraft pulp, formed into linerboard on a fourdrinier machine.

BATCH FED INCINERATOR: An incinerator that is charged with refuse periodically, the charge being allowed to burn down or burn out before another charge is added.

BEL: Ten decibels.

BESSEMER PROCESS: A process for making steel from cast iron. Molten iron from the blast furnace is run into the Bessemer converter, a large egg-shaped vessel with holes below. Through these, air is blown into the molten metal, and the carbon is oxidized. The requisite amount of spiegel is then added to introduce the correct amount of carbon for the type of steel required.

BINDER: See Core binder.

BITUMINOUS COAL: Soft coal, dark brown to black in colour, having a relatively high proportion of gaseous constituents and usually burning with a smoky luminous flame.

BLAST FURNACE: Furnace for the smelting of iron from iron oxide ores. Constructed of refractory bricks covered with steel plate. Charged from above with a mixture of the ore, limestone (CaCO_3), and coke. The coke is ignited at the bottom of the furnace by a blast of hot air; the carbon monoxide so produced reduces the iron oxide to iron, while the heat of the action decomposes the limestone into carbon dioxide and lime, CaO . The lime combines with the sand and other impurities in the ore to form a molten slag. The molten iron and the slag are tapped off at the bottom of the furnace. The resulting pig-iron or cast iron contains up to 4.5% carbon.

BLEEDER: A bypass or relief valve used to relieve excess pressure.

BLISTER COPPER: An impure intermediate product in the refining of copper, produced by blowing copper bearing material in a converter; the name is derived from the large blisters on the cast surface that result from the liberation of SO_2 and other gases.

BLOWBACK: The difference between the pressure at which a safety valve opens and at which it closes, usually about three per cent of the pressure at which the valve opens.

BLOWDOWN: Hydrocarbons purged during refinery shutdowns and startups which are manifolded for recovery, safe venting, or flaring.

BOILER: A closed pressure vessel in which the liquid, usually water, is vaporized by the application of heat.

BOILER HORSEPOWER: A unit of rate of water evaporation. One boiler horsepower equals the evaporation of 34.5 lb. of water per hour from a temperature of 100°C into dry saturated steam at the same temperature (equivalent to 33,472 btu per hour).

BRASSES: Copper-based alloy of 60-65% copper. Alloying material is usually zinc.

BREECHING: A sheet-iron or sheet-metal casing at the end of boilers for conveying the smoke from the flues to the smokestack.

BRIGHTENING: The process of producing bright stock (see bright stock)

BRIGHT STOCK: Refined high viscosity lubricating oils usually made from residual stocks by suitable treatment, such as a combination of acid treatment or solvent extraction with dewaxing or clay finishing.

BRITISH THERMAL UNIT (Btu): Quantity of heat required to raise the temperature of 1 lb. of water through 1° Fahrenheit, 251.98 calories.

BRONZES: Copper based alloy of 85-90% copper. Alloying material is usually tin.

BUNKER C OIL: Residual fuel oil of high viscosity commonly used in marine and stationary power plants (No. 6 fuel oil).

BURNER: A device for the introduction of fuel and air into a furnace at the desired velocities, turbulence, and concentration, to establish and maintain proper ignition and combustion of the fuel.

BUSS (BUSBAR): A heavy metal conductor, usually copper, for high amperage electricity.

BUSTLE PIPE: In steel making, a metal tube of large diameter which surrounds a blast furnace at a level a little above the tuyeres; it is lined with refractory material and distributes the hot air from the blast stoves to the pipes (goosenecks) which carry the air to the tuyeres.

BY-PRODUCT: Substance obtained incidentally during the manufacture of some other substance. Often as important as the manufactured substance itself, e.g. the by-products of coal-gas manufacture include ammonia, ccal-tar, and coke.

CALCINATION: Strong heating; conversion of metals into their oxides by heating in air.

CALCINE: Ore or concentrate which has been treated by calcination or roasting and which is ready for smelting.

CALCINING: Roasting of ore in an oxidizing atmosphere usually to expel sulphur or carbon dioxide. If sulphur removal is carried to practical completion, the operation is termed "sweet roasting"; if all CO₂ is removed, the operation is termed dead roasting.

CALORIE: The mean calorie is 1/1000 of the heat required to raise the temperature of one gram of water from 0°C to 100°C at a constant atmospheric pressure. It is about equal to the quantity of heat required to raise one gram of water 1°C.

CARBON BLACK: Finely divided form of pure carbon, obtained by the incomplete combustion of natural gas. Used in the manufacture of inks, rubber products, and some plastics.

CARBON DIOXIDE: carbonic acid gas. CO_2 . Colourless gas with faint tingling smell and taste. Occurs in the atmosphere; formed by the oxidation of carbon and carbon compounds. Utilized by plants. See photosynthesis. Forms a solid at -78.5 C at atmospheric pressure, and is used as a refrigerant in this form as dry-ice, for the preservation of frozen foods, etc. As carbon dioxide gas is heavier than air and does not support combustion, it is used in fire extinguishers.

CARBON LOSS: The loss representing the unliberated thermal energy caused by failure to oxidize some of the carbon in the fuel.

CARBONIZATION: The process of converting coal to carbon in the absence of air by using intense heat to remove volatile ingredients.

CARCINOGENIC: Producing or tending to produce cancer.

CARRYOVER: The chemical solids and liquid entrained in the steam from a boiler or effluent from a fractionating column, absorber, or reaction vessel.

CATALYSIS: The alteration of the rate at which a chemical reaction proceeds, by the introduction of a substance (catalyst) which remains unchanged at the end of the reaction. Small quantities of the catalyst are usually sufficient to bring the action about or to produce a vast increase in its speed.

CATALYST: Substance which alters the rate at which a chemical reaction occurs, but is itself unchanged at the end of the reaction. Catalysts are widely used in the chemical industry; metals in a finely divided state, and oxides of metals, are frequently used. The enzymes are organic catalysts produced by living cells.

CATALYTIC CRACKING: The use of a catalyst to bring about the cracking of high boiling mineral oils.

CATHODE: In aluminum production, the negatively charged terminal of the reduction cell to which the aluminum migrates. The terminal consists of the carbon lining that makes up the bottom of the cell.

CAVING: In metal mining, caving implies the dropping of the over-burden as part of the system of mining.

CELSIUS TEMPERATURE SCALE: The same as the centigrade scale of temperature.

CENTRIFUGE: Apparatus for separating particles from a suspension. Balanced tubes containing the suspension are attached to the opposite ends of arms rotating rapidly about a central point; by centrifugal force the suspended particles are forced outwards, and collect at the bottoms of the tubes.

CHANGE OF STATE (phys.): The conversion of a substance from one of the physical states of matter (solid, liquid, or gas) into another, e.g. the melting of ice.

CHARCOAL: General name for numerous varieties of carbon, usually impure; generally made by heating vegetable or animal substances with exclusion of air. Many forms are very porous and adsorb various materials readily. See activated carbon.

CHARGING: Feeding raw material into an apparatus, for example, into a furnace, for treatment or conversion.

CHLORINE: Cl. Element. A.W. 35.453. At.No.17. Greenish-yellow gas with a choking irritating smell. Poisonous; first poison gas to be used in warfare (by Germany, Ypres, 1915). Compounds occur as common salt (sodium chloride), NaCl, in sea-water and as rock salt; and as chlorides of other metals. Manufactured almost entirely by the electrolysis of brine. Used in the manufacture of bleaching powder, disinfectants, hydrochloric acid. Also used as a germicide in drinking-water.

CHLOROSIS: A diseased condition in green plants marked by yellowing or blanching of the leaves.

CHROMIUM PLATING: Deposition of a thin, resistant film of chromium metal by electrolysis from a bath containing a solution of chromic acid, Cr₂O₃.

CHUTE, CHARGING (INCINERATOR): A pipe or duct through which wastes are conveyed by gravity from above to a primary chamber or to storage facilities preparatory to burning.

CINDERS: Particles not ordinarily considered as fly-ash or dust because of their greater size; these particles consist essentially of fused ash and/or unburned matter.

CLEANING FIRES: The act of removing ashes from the fuel bed or furnace.

CLINKERS, CEMENT: The glassy, stony, lump-like product of fusing together clay and limestone as the first stage in the manufacture of portland cement.

COAL: Material, occurring in large underground deposits, consisting of carbon and various carbon compounds. Formed by the decomposition of vegetable matter during periods of many millions of years. The main types of coal are: peat, lignite, ordinary or bituminous coal, and anthracite.

COAL DESULPHURIZATION: See desulphurization.

COAL-GAS: Fuel gas manufactured by the destructive distillation of coal in closed iron retorts; often supplemented with water-gas. Composition by volume (average values): hydrogen 50%, methane (CH_4) 30%, carbon monoxide (CO) 8%, other hydrocarbons 4%, nitrogen, carbon dioxide, and oxygen 8%.

COAL-GAS BY-PRODUCTS: Amongst the valuable substances obtained during the manufacture of coal gas are coke, coal-tar, ammonia, sulphuric acid, and pitch.

COAL-TAR: Thick black oily liquid obtained as a by-product of coal-gas manufacture. Distillation and purification yields, amongst other valuable products: benzene, C_6H_6 ; toluene, $\text{C}_6\text{H}_5\text{CH}_3$; xylene, $\text{C}_6\text{H}_4(\text{CH}_3)_2$; phenol, $\text{C}_6\text{H}_5\text{OH}$; naphthalene, C_{10}H_8 ; cresol, $\text{CH}_3\text{C}_6\text{H}_4\text{OH}$, and anthracene, $\text{C}_{14}\text{H}_{10}$. Pitch is left as a residue.

COKE: Greyish, porous brittle solid containing about 80% carbon. Obtained as a residue in the manufacture of coal-gas ('gas coke'); also made specially in coke ovens, in which the coal is treated at lower temperatures than in gas manufacture.

COKE BREEZE: Fine coke particles leaving the coke quencher with the quenched coke by conveyor. The particles are very fine and may be blown away.

COKE, PETROLEUM: The solid carbonaceous residue remaining as the final product of the condensation processes in cracking. It consists of highly polycyclic aromatic hydrocarbons very poor in hydrogen. It is used extensively in metallurgical processes. Calcination of petroleum coke can yield almost pure carbon or artificial graphite suitable for production of electrodes, motor brushes, dry cells, etc.

COKING: 1. Carbonization of coal by destructive distillation. 2. In petroleum refining: any cracking process in which the time of cracking is so long that coke is produced as the bottom product; thermal cracking for conversion of heavy, low-grade oils into lighter products and a residue of coke; or the undesirable building up of coke or carbon deposits on refinery equipment.

COLLECTION EFFICIENCY: The ratio of the weight of pollutant collected to the total weight of pollutant entering the collector.

COLLOID: 1. A substance composed of extremely small particles, ranging from 0.005 micrometres to 0.2 micrometres, which when mixed with a liquid will not settle, but will remain suspended. The colloidal suspension thus formed has properties that are quite different from the simple solution of the two substances. 2. In fuel burning, a finely divided organic substance which tends

to inhibit the formation of dense scale and results in the deposition of sludge, or causes it to remain in suspension, so that it may be blown from the boiler.

COLLOIDAL FUEL: Mixture of fuel oil and powdered solid fuel.

COMBINATION BOILER: A combustion unit used to produce steam for process or electrical energy which is designed to burn bark and at least one other fuel.

COMBUSTION: The chemical combination of oxygen and combustible matter resulting in the rapid release of energy and products of combustion (incompletely burned organic species, CO, CO_2 , H_2O , NO_x , etc.).

COMBUSTION CONTAMINANTS: Particulate matter discharged into the atmosphere from the burning of any kind of material containing carbon.

COMBUSTION TOWER: Refractory graphite-lined or water-jacketed stainless steel tower in which phosphorus is burned to phosphorus pentoxide.

CONDENSED FUMES: Minute solid particles generated by the condensation of vapours from solid matter after volatilization from the molten state, or generated by sublimation, distillation, calcination, or chemical reaction when these processes create airborne particles.

CONTACT CONDENSER: A condenser in which coolant, vapours, and condensate are mixed.

CONTINUOUS-FEED INCINERATOR: An incinerator into which refuse is charged in a nearly continuous manner in order to maintain a steady rate of burning.

CONVECTION: Transference of heat through a liquid or gas by the actual movement of the fluid. Portions in contact with the source of heat become hotter, expand, become less dense and their place is taken by colder portions, thus setting up convection currents.

CONVERTER: 1. A furnace in which air is blown through a bath of molten metal or matte, oxidizing the impurities and maintaining the temperature through the heat produced by the oxidation reaction. 2. In nitric acid production, the chamber in which ammonia is converted to nitric oxide and water by reacting it with air over a platinum-rhodium catalyst.

CONVERTING: The process of removing impurities from molten metal or metallic compounds by blowing air through the liquid. The impurities are changed either to gaseous compounds, which are removed by volatilization, or to liquids or solids which are removed as slags.

COPPER: Cu. Element. A.W.63.54. At.No.29. Red metal, m.p. 1084° C., S.G. 8.95. Very malleable and ductile; after silver, the best conductor of electricity. Unaffected by water or steam. Occurs as the free metal, and as cuprite or ruby ore, Cu_2O ; copper glance, Cu_2S ; copper pyrites CuFeS_2 . Extracted from sulphide ores by alternate roasting and fusing with sand, thus removing iron and volatile impurities, and leaving a mixture of cuprous oxide and sulphide. This is then heated in a reverberatory furnace, giving impure copper, which is then refined by various methods. Used for steam boilers, electrical wire and apparatus in electrotyping, and in numerous alloys, e.g. bronze, brass, speculum metal, gun metal, bell metal, Dutch metal, manganin, constantan, nickel silver, German silver, etc.

CORE: The central part of a sand mold as used in foundries. The device placed in a mold to make a cavity in a casting.

CORE BINDER: Organic material added to foundry sand to aid in formation of a strong core for casting. Flour, linseed oil, starch, and resins are among materials used.

CORROSION: Surface chemical action, especially on metals, by the action of moisture, air, or chemicals.

CRACKING (chem.): pyrolysis. Decomposition of a chemical substance by heat; especially the conversion of mineral oils of high boiling point into more volatile oils suitable for gasoline engines, by 'cracking' the larger molecules of the heavy oils into smaller ones.

CRACKLINGS: The crisp residue left after the fat has been separated from the fibrous tissue in rendering lard or frying or roasting the skin of pork, turkey, duck, or goose.

CRUCIBLE: Vessel of heat-resisting material used for containing high-temperature chemical reactions.

CRUSHER: A machine for crushing rock or other materials. Among the various types of crushers are the ball mill, gyratory crusher, Hadsel mill, hammer mill, jaw crusher, red mill, rolls, and stamp mill.

CRYOLITE: Sodium aluminum fluoride (Na_3AlF_6) used as an electrolyte in smelting of alumina to provide aluminum.

CULM: The fine refuse from anthracite coal production.

CUPELLATION: Separation of silver, gold, and other noble metals from impurities which are oxidized by hot air. The impure metal is placed in a cupel, a flat dish made of porous refractory material, and a blast of hot air is directed upon it in a special furnace. The impurities are oxidized by the air and are partly swept away by the blast and partly absorbed by the cupel.

CUPOLA: A vertical shaft furnace used for melting metals, especially grey iron, by having the charge come in contact with the hot fuel, usually metallurgical coke. Metal, coke, and flux are charged from the top of the furnace onto a bed of hot coke through which air is blown.

CURTAIN WALL: A partition wall between chambers in an incinerator under which combustion gases pass.

CYCLONE: A structure without moving parts in which the velocity of an inlet gas stream is transformed into a confined vortex from which centrifugal forces tend to drive the suspended particles to the wall of the cyclone body. The particles then slide down the cyclone wall and are collected at the bottom.

CYCLONE SCRUBBERS: Devices ranging from simple dry cyclones with spray nozzles to multistage devices. All feature a tangential inlet to a cylindrical body.

CYCLONIC SPRAY TOWER: Liquid scrubbing apparatus where sprays are introduced countercurrent to gases for removal of contaminants.

DECIBEL: One tenth of a bel. A unit which compares levels of power. Two power levels, P_1 and P_2 , are said to differ by n decibels when:

$$n = 10 \log_{10} \frac{P_2}{P_1}$$

This unit is often used to express sound intensities. In this case, P_2 is the intensity of the sound under consideration and P_1 is the intensity of some reference level, often the intensity of the lowest audible note of the same frequency.

DECOMPOSITION (chem.): Breaking up of a chemical compound, e.g. mercuric oxide, HgO , decomposes on heating into mercury and oxygen. Also used in relation to the breaking up of organic materials as a result of the action of bacteria, fungi, or chemicals.

DEHYDROGENATION: The removal of hydrogen from a chemical compound; for example, the removal of two hydrogen atoms from butane to make butylene, and the further removal of hydrogen to make butadiene.

DEMISTER (COLLECTOR): 1. A mechanical device used to eliminate finely divided liquid particles from process streams by impaction and agglomeration. 2. Apparatus made of wire mesh or glass fibre and used to eliminate acid mist as in the manufacture of sulphuric acid.

DESTRUCTIVE DISTILLATION: Carbonization. Heating a complex substance to produce chemical changes in it, and distilling off the volatile substances so formed, e.g. the destructive distillation of coal produces coal-gas and many other valuable products.

DESULPHURIZATION: 1. In coal processing, the removal of sulphur from the coal, often by mechanical cleaning processes. 2. In petroleum refining, removing sulphur compounds from a charge stock (oil that is to be treated in a particular unit).

DIFFUSION: The spreading or scattering of a gaseous or liquid material. 1. Eddy diffusion; diffusion caused by turbulent activity in a fluid system. 2. Molecular diffusion: a process of spontaneous intermixing of different substances, attributed to molecular motion and tending to produce uniformity of concentration.

DIRECT-FIRED BOILER: Commonly used to denote a boiler and furnace fired by pulverized coal.

DISPERSION: The dilution of a pollutant by diffusion, or turbulent action, etc. Technically, a two-phase system of two substances, one of which (the dispersed phase) is uniformly distributed in a finely divided state through the second substance (the dispersion medium). Either phase may be a gas, liquid, or solid.

DISTILLATE: Liquid obtained by condensation of vapour in distillation.

DISTILLATE FUELS: Liquid fuels distilled usually from crude petroleum, except residuals such as No. 5 and No. 6 fuel oil.

DISTILLATE OILS: The lighter oils produced by distilling crude oil.

DISTILLATION: Process of converting a liquid into vapour, condensing the vapour, and collecting the condensed liquid or distillate. Used for separating mixtures of liquids of different boiling points or for separating a pure liquid from a non-volatile constituent. (See fractional distillation) Also used in the separation of isotopes.

DIURNAL: Daily; performed or completed once every 24 hours.

DOCTOR TREATMENT: Treatment of gasoline with sodium-plumbite solution and sulphur to improve its odour.

DOPES FOR GASOLINES: Materials added in small amounts to gasoline to increase the octane number and thus help to prevent knocking.

DOUBLE DECOMPOSITION: A chemical reaction between two compounds in which part of the first compound becomes united with the remainder of the second, as: AB + CD = AD + BC.

DRAUGHT: A gas flow resulting from the pressure difference between the incinerator, or any component part, and the atmosphere, which moves the products of combustion from the incinerator to the atmosphere.

1. Natural draught: the negative pressure created by the difference in density between the hot flue gases and the atmosphere. 2. Induced draught: the negative pressure created by the vacuum action of a fan or blower located between the incinerator and the stack. 3. Forced draught: the positive pressure created by the action of a fan or blower, which supplies the primary or secondary air.

DROP ARCH: A refractory construction or baffle which serves to deflect gases in a downward direction.

DROSS: 1. Impurity formed in melted metal. A zinc-and-iron alloy forming in a bath of molten zinc, in galvanizing iron. 2. The scum that forms on the surface of molten metals usually due to oxidation, but occasionally due to the rising of impurities to the surface.

DRUM, FLASH (OR FLASH TOWER): A drum or tower into which the heated outlet products of a preheater or exchanger system are conducted, often with some release in pressure. The purpose of the drum is to allow vaporization and separation of the volatile portions for fractionation elsewhere.

DRY BOTTOM FURNACE: A furnace designed to burn pulverized coal at temperatures low enough to prevent the ash from fusing or slagging.

DUST: Generally particles from 1 to 100 micrometres in size that become airborne by natural or mechanical means. These particles do not diffuse but will settle under the influence of gravity.

DUST COLLECTING FAN: A centrifugal fan which concentrates dust and skims it into a cyclone or hopper.

DUSTLESS LOADING: The amount of dust in a gas, usually expressed in grains per cubic foot or in pounds per thousand pounds of gas (see also grain loading).

ECOLOGY: The study of the relation of plants and animals to their environment.

ECONOMIZER: A heat recovery device designed to transfer heat from the products of combustion to a fluid, usually feedwater for a steam boiler. The water flows through a bank of tubes placed across the flue gases and is heated by these gases prior to entering the boiler.

EFFECTIVE STACK HEIGHT: The sum of the stack height and the plume rise.

EFFICIENCY: The ratio of output to input. The efficiency of a steam generating unit is the ratio of the heat absorbed by the water or steam to the heat in the fuel fired, expressed as a percentage.

EFFLUENT: Any waste material (solid, liquid, gas) emitted by a process.

EFFLUENT WATER SEPARATOR: A container designed to separate volatile organic compounds from waste water prior to discharge or reuse.

ELECTRODE: Conductor by which an electric current enters or leaves an electrolyte in electrolysis, an electric arc or a vacuum tube (see discharge in gases and thermionic valve): the positive electrode is the anode, the negative one the cathode. In a semi-conductor device, an element which emits or collects electrons or holes, or controls their movement by an electric field.

ELECTROLYSIS: Chemical decomposition of certain substances (electrolytes) by an electric current passed through the substance in a dissolved or molten state. Such substances are ionized (see ionic hypothesis) into electrically charged ions, and when an electric current is passed through them by means of conducting electrodes, the ions move towards the oppositely charged electrodes, there give up their electric charges, become uncharged atoms or groups, and are either liberated or deposited at the electrode, or react chemically with the electrode, the solvent, or each other, according to their chemical nature.

ELECTROPLATING: Depositing a layer of metal by electrolysis, the object to be plated forming the cathode in an electrolytic tank or bath containing a solution of a salt of the metal which is to be deposited.

ELECTROSTATIC PRECIPITATOR: Devices that separate particles from a gas stream by passing the carrier gas between two electrodes across which a uni-directional, high-voltage electrical charge is placed. The particles pass through this field, become charged and migrate to the oppositely charged electrode. Single-stage precipitators are those in which gas ionization and particulate collection are combined into a single step. In the two-stage unit, ionization is achieved by one element of the

unit and the collection by the other. Electrostatic precipitators are highly efficient collectors for minute particles.

ELECTROSTATIC PRECIPITATION: A widely used method of controlling the pollution of air (or other gases). The gas, containing solid or liquid particles suspended in it, is subjected to a uni-directional electrostatic field, so that the particles are attracted to, and deposited upon, the positive electrode.

ELUTRIATION: The washing, separation, or sizing of fine particles of different weight by suspending them in a current of air or water.

ELUTRIATOR: A vertical tube through which a gas or fluid passes upward at a specific velocity while a solid mixture whose separation is desired is fed into the top of the column. The large particles which settle at a velocity higher than that of the rising fluid are collected at the bottom of the column, and the smaller particles are carried out of the top of the column with the fluid.

EMISSION: The total amount of a solid, liquid, or gaseous pollutant emitted into the atmosphere from a given source in a given time, and indicated in grams per cubic metre of gas, pounds per hour, or other quantitative measurement.

EMISSION FACTOR: A typical value to indicate normal amounts of pollutants released from a given emission source when operated using specified control procedures and devices.

EMPHYSEMA, PULMONARY: An overdistension of lung air spaces resulting in destruction of the lung alveoli and other functioning tissues.

ENDOTHERMIC REACTION: A reaction which requires the addition of heat for its continuation.

ENTRAINMENT: The process of particulates or other materials being carried along by a gas stream.

EPIDERMIS: Outer covering (skin) on animals or plants.

ESTERIFICATION: Formation of an ester by the chemical reaction of an acid with an alcohol; e.g. the action of ethyl alcohol on acetic acid to form ethyl acetate and water.

ESTERS: Organic compounds corresponding to inorganic salts, derived by replacing hydrogen of an acid by an organic radical or group; e.g. ethyl acetate, $\text{CH}_3\text{COOC}_2\text{H}_5$, is the ethyl ester of acetic acid, CH_3COOH . Many esters are pleasant smelling liquids for flavouring essences. Many vegetable and animal fats and oils also belong to this class.

EVAPORATOR: Usually a vessel which receives the hot discharge from a heating coil and, by a reduction in the pressure, flashes off overhead the light products and allows the heavy residue to collect in the bottom (see flash tower).

EXCESS AIR: Air supplied for combustion in excess of that theoretically required for complete combustion, usually expressed as a percentage of theoretical air, such as "130 per cent excess air".

EXMOSIS: Outward osmotic flow. See osmosis.

EXOTHERMIC PROCESS: Process in which energy in the form of heat is released.

EXOTHERMIC REACTION: A reaction which produces heat.

EXTRACTION: The process of separating a desired constituent from a mixture, by means of selective solubility in an appropriate solvent. Also used to describe any process by which a pure metal is obtained from ore.

FABRIC FILTER: See bag filter.

FEEDSTOCK: Starting material used in a process. This may be raw material or an intermediate product that will undergo additional processing.

FERMENTATION: Chemical change brought about in organic substances by living organisms (yeast, bacteria, etc.) by enzyme action. Usually applied to the alcoholic fermentation produced by the action of zymase on certain sugars, giving alcohol and carbon dioxide according to the equation:



FILTRATE: Clear liquid after filtration; substance which has been filtered, containing no suspended matter.

FISCHER-TROPSCH PROCESS: A process for the manufacture of hydrocarbon oils from coal, lignite, or natural gas. The process essentially consists of the hydrogenation of carbon monoxide, CO, in the presence of catalysts; this results in the formation of hydrocarbons and steam.

FIXED CARBON: That part of the carbon which remains when coal is heated in a closed vessel until the volatile matter is driven off. It is the non-volatile matter minus the ash.

FLARE: A device utilized at petroleum refineries, heat treating operations, liquified petroleum gas facilities, etc., to burn rich mixtures of combustible waste gases. A flare differs from "afterburner" in that no auxiliary fuel other than a pilot flame is necessary to incinerate the gases.

FLOATING ROOF: A special tank roof which floats upon the oil in a storage tank.

FLOCCULATION: The coagulation of finely divided particles into particles of greater mass.

FLOTATION PROCESS: Separation of a mixture, e.g. of zinc blende, ZnS, and galena, PbS, making use of the surface tension of water. Zinc blende is not easily wetted by water and floats, supported by the surface film of water, while galena sinks. In modern practice, special materials are added to the water which cause one of the constituents to float in the froth produced by aerating and agitating the water.

FLUE GAS: The gaseous products of combustion from a boiler furnace consisting predominantly of carbon dioxide, carbon monoxide, oxygen, nitrogen and steam. Analysis of the flue gases is used to check the efficiency of the furnace.

FLUE-FED INCINERATOR: An incinerator which is charged (refuse is conveyed by gravity to the primary chamber) through a vertical flue which also serves as the passage for conducting products of combustion to the atmosphere.

FLUIDIZED ROASTING: Oxidation of finely ground pyritic minerals by means of upward currents of air, blown through a reaction vessel (fluid bed roaster) with sufficient force to cause the bed of materials to expand (boil). Reaction between mineral and air is maintained at a desired exothermic level by control of oxygen entry, by admission of cooling water, or by addition of fuel.

FLUORINE: F. Element. A.W. 18.9984. At. No. 9. Pale yellowish-green gas, resembling chlorine but more reactive. Occurs combined as fluorospar and as cryolite. Made by the electrolysis of a solution of potassium hydrogen fluoride in anhydrous hydrogen fluoride. The fluorine organic compounds, made by replacing hydrogen in organic compounds by fluorine, are assuming considerable industrial importance.

FLUOROSIS: A chronic poisoning resulting from the presence of 0.9 milligrams or more per litre of fluorine in drinking water. Teeth become brittle and opaque white with a mottled enamel.

FLUOROSPAR: A natural calcium fluoride (CaF_2) used as a flux in open hearth steel furnaces and in gold, silver, copper, and lead smelting.

FLUX: 1. In chemistry and metallurgy, a substance that promotes the fusing of minerals or metals or prevents the formation of oxides. 2. A substance added to a solid to increase its fusibility. 3. A substance to reduce melting temperature. 4. Any chemical or rock added to an ore to assist in its reduction by heat, such as limestone with iron ore in a blast furnace.

FLY-ASH: In incineration, suspended incombustible particles, charred paper, soot, dust, or other partially incinerated matter, carried in the gaseous products of combustion.

FOAM: A colloidal suspension of a gas in a liquid.

FOG: Effect caused by the condensation of water vapour upon particles of dust, soot, etc.

FOOD-GRADE ACID: Phosphoric acid that has been treated for removal of heavy metals and is suitable for use in food products.

FORCED DRAUGHT: See draught.

FORMALDEHYDE: HCHO. A gas with an irritating smell, very soluble in water. 40% solution is known as formalin. Made by the oxidation of methyl alcohol. Used in the manufacture of plastics and dyes, in the textile industry, in medicine, and as a disinfectant.

FOSSIL FUELS: Coal, petroleum and natural gas.

FRACTIONAL DISTILLATION: Fractionation. Separation of a mixture of several liquids which have different boiling points, by collecting separately 'fractions' boiling at different temperatures.

FRASCH PROCESS: For the extraction of sulphur. Used to extract sulphur from deposits deep down under sand. A series of concentric pipes is sunk down to the level of the sulphur deposit, superheated steam is forced down to melt the sulphur, which is then forced to the surface by compressed air blown down the centre pipe.

FUEL: Any form of combustible matter - solid, liquid, vapour, or gas, excluding combustible refuse.

FUEL-BURNING EQUIPMENT: Any furnace, boiler, apparatus, stack, and all appurtenances thereto, used in the process of burning fuel for the primary purpose of producing heat or power by indirect heat transfer.

FUGITIVE DUST: Solid airborne particulate matter emitted from any source other than a flue or stack.

FUME: Fine solid particles predominately less than 1 micrometre in diameter suspended in a gas. Usually formed from high-temperature volatilization of metals, or by chemical reaction.

FUMIGATION: Fumigation is an atmospheric phenomenon in which pollution, which has been retained by an inversion layer near its level of emission, is brought rapidly to ground level when the inversion breaks up. High concentrations of pollutant can thus be produced at ground level. Under certain conditions can also occur downwind of a source, the plume reaching ground level.

FUMING NITRIC ACID: A mixture of 98 per cent nitric acid and an equilibrium mixture of nitrogen tetroxide (N_2O_4) and nitrogen oxide (NO).

FURNACE OIL: A distillate fuel primarily intended for domestic heating use. No. 1 commercial standard grade is intended for "vaporizing" burners requiring a volatile fuel, whereas No. 2 commercial standard grade is less volatile, and is thus usable in the "atomizing" types of burner.

FUSEL OIL: Mixture of butyl and iso-amyl alcohols ($C_4H_9OH, C_5H_{11}OH$) together with other organic substances; a liquid of unpleasant smell and taste; by-product of the distillation of alcohol produced by fermentation.

FUSIBLE ALLOYS: Alloys of low melting point; generally eutectic mixtures of metals of low melting points such as bismuth, lead, tin and cadmium. Wood's metal and Lipowitz alloy both contain all four and melt below the boiling point of water. Fusible alloys having a melting point a little above the boiling point of water are used in the construction of automatic sprinklers; heat from a fire melting the metal and releasing a spray of water.

GAUGE PRESSURE: The pressure above atmospheric pressure, expressed as pounds per square inch, gauge (psig).

GAS LAWS: Statements as to the volume changes of gases under the effect of alterations of pressure and temperature. Boyle's law states that at constant temperature the volume of a given mass of gas is inversely proportional to the pressure; i.e. $pv = \text{constant}$. Charles's law states that at constant pressure all gases expand by $1/273$ of their volume at 0°C . for a rise in temperature of 1°C ., i.e. the volume of a given mass of gas at constant pressure is directly proportional to the absolute temperature. The two laws may be combined in the expression $pv \propto T$, where T is the absolute temperature; or, for a gram-molecule of gas, $pv = RT$. This gives the behaviour of a gas when both temperature and pressure are altered. The gas laws are not perfectly obeyed by ordinary gases, being strictly true only for the perfect gas.

GAY-LUSSAC'S LAW OF GASEOUS COMBINATION: When gases combine, they do so in a simple ratio by volume to each other, and to the gaseous product, measured under the same conditions of temperature and pressure. Explained by Avogadro's law.

GEL: Colloidal solution which has set to a jelly, the viscosity being so great that the solution has the elasticity of a solid. Formation attributed to a mesh-like structure of the disperse phase or colloid, with the dispersion medium circulating through the meshwork.

GOB PILES: Large piles of low-combustible refuse from coal mine preparation plants. Fires may develop in these waste material piles by liberation of heat through slow oxidation, until ignition temperature is reached.

GRAIN LOADING: Concentration of particulates in exhaust gas, expressed as grains per standard cubic foot (700 grains = 1 pound).

GRAVITATION SETTLING: Removal of material from the atmosphere due to the action of gravity.

GREEN COKE: Coke that has not been fully cooked. Green coke produces excessive emissions when pushed from a coke oven.

GREEN FEED: (Calcined Feed) Not fully processed or treated feed.

HALF-LIFE: Half-value period. The time taken for the activity of a radioactive isotope to decay to half its original value, that is, for half of the atoms present to disintegrate. Half-lives vary from isotope to isotope, some being less than a millionth of a second and some more than a million years.

HEAT ISLAND EFFECTS: Meteorological characteristics of an urban area or large industrial complex which differentiates it from its surroundings. Generally, the urban area has (1) higher temperatures, (2) a less stable nocturnal lapse rate immediately above the surface, (3) lower relative humidities, (4) greater cloudiness, (5) more frequent fogs, (6) less incoming radiation, (7) lower wind speeds, and (8) greater precipitation.

HEAT RELEASE RATE: The amount of heat liberated during the process of combustion and expressed in Btu per hour per cubic foot of internal furnace volume in which the combustion takes place.

HEAVY WATER: Deuterium Oxide. D_2O . Water in which the hydrogen is replaced by deuterium. Present in natural water to the extent of about 1 part in 5,000. The term is also used when referring to water which contains appreciably more D_2O or DHO than natural water. Heavy water is used as a moderator in dome nuclear reactors.

HOT BLAST MAIN: A dust lined with refractory material, through which hot air passes from a hot blast stove to the bustle pipe of a blast furnace.

HOT WELL: A reservoir for receiving warm condensed steam drawn from a condenser.

HUMUS: Dark brown colloidal matter present in soil as the result of animal and vegetable decomposition. Important source of mineral nutrients for plants.

HYDRATOR-ABSORBER: A single or double tower in which phosphorus pentoxide is hydrated to phosphoric acid and the resulting acid mist is absorbed.

HYDRAULIC FLY-ASH HANDLING: A system using water-filled pipes or troughs in which fly-ash is conveyed by means of gravity, water jets, or centrifugal pumps.

HYDROCARBONS: Organic compounds which contain only carbon and hydrogen. Classified as either aliphatic or aromatic compounds (or a combination of both). Hydrocarbons may be either saturated or unsaturated compounds.

HYDROCRACKING: A low-temperature catalytic method of converting crude oil, residual oil, petroleum tar, and asphalt to high-octane gasoline, met fuel, and/or high-grade fuel oil. The process combines cracking, hydrogenation, and isomerization.

HYDROGEN ION CONCENTRATION: Number of grams of hydrogen ions per litre of solution. Useful as a measure of the acidity of a solution and in this context is usually expressed in terms of

$$Ph = \log_{10} \frac{1}{(H^+)}$$

where (H^+) is the hydrogen ion concentration. As pure water at ordinary temperatures dissociates slightly into hydrogen ions and hydroxyl ions, the concentration of each type of ion being 10^{-7} gram-molecules per litre, the pH of pure water will be

$$\log_{10} \frac{1}{10^{-7}} = 7; \quad \text{this figure}$$

is accordingly taken to represent neutrality on the pH scale. If acid is added to water its hydrogen ion concentration will increase and its pH will therefore decrease. Thus a pH below 7 indicates acidity and a pH in excess of 7 indicates alkalinity.

HYDRODESULPHURIZATION: A desulphurization process in which the oil is heated with hydrogen.

HYDROGEN SULPHIDE: Sulphuretted hydrogen, H_2S . Colourless poisonous gas with a smell of bad eggs. Formed by the decomposition of organic material containing sulphur; occurs naturally in some mineral waters. Prepared by the action of dilute acids on sulphides of metals; used in chemical analysis.

HYDROGENATION: Subjecting to the chemical action of, or causing to combine with, hydrogen.

HYDROGENATION OF COAL: The manufacture of artificial mineral oil from coal by the action of hydrogen; causing the carbon in coal to combine with hydrogen to form hydrocarbons. See Fischer-Tropsch Process.

HYDROGENATION OF OILS: Artificial hardening of liquid animal and vegetable oils by the action of hydrogen. Liquid fats and oils contain a high percentage of liquid triolein, $C_{57}H_{104}O_6$, which may be converted into a solid tristearin, $C_{57}H_{110}O_6$, by the action of hydrogen in the presence of finely divided nickel which acts as a catalyst; the result being a hard fat of higher melting point.

HYDROMETALLURGY: The treatment of ores, concentrates, and other metal-bearing materials by wet processes, usually involving the solution of some component, and its subsequent recovery from the solution.

HYDROTREATING: A treating process using hydrogen for the desulphurization of cracked distillates.

HYPERTONIC: A solution is said to be hypertonic with respect to another if it has greater osmotic pressure.

IMMISCIBLE: Incapable of being mixed to form a homogeneous substance; usually applied to liquids; e.g. oil and water are immiscible.

IMPERMEABLE: Not permitting the passage of fluids.

IMPINGEMENT: In air sampling, impingement refers to the process for the collection of particulate matter in which the gas being sampled is directed forcibly against a surface. 1. Dry impingement: the process of impingement in the gas stream where particulate matter is retained upon the surface against which the stream is directed. The collecting surface may be treated with a film of adhesive. 2. Wet impingement: the process of impingement in a liquid which retains the particulate matter.

IMPINGEMENT SEPARATORS: Devices using the principle that when a gas stream carrying particulate matter impinges on a body, the gas is deflected around the body, while the particles, because of their greater inertia, tend to strike the body and be collected on its surface. The bodies may be in the form of plates, cylinders, ribbons, or spheres.

INCINERATION: The process of burning solid, semi-solid, or gaseous combustible waste.

INCINERATOR: An apparatus designed to burn solid, semi-solid, or gaseous waste leaving little or no combustible material (see multiple chamber incinerator).

INERTIAL SEPARATOR: The most widely used device for collecting medium and coarse sized particles. Inertial separators operate by the principle of imparting centrifugal force to the particle to be removed from the carrier gas stream.

INORGANIC: Of mineral origin; not belonging to the large class of carbon compounds which are termed organic.

INTERRUPTIBLE GAS: Gas sold whereby the seller may curtail or stop delivery, generally at his option. The gas customer under these conditions is expected to have standby equipment capable of taking over 100% of his needs by an alternate fuel.

INVERSION: A stratum in the atmosphere through which the temperature increases with height. The layer is thermally stable and vertical motion within the layer is suppressed.

INVERSION BASE: The lowest height in the atmosphere at which the temperature ceases to decrease with height.

ISOMERIZATION: A reaction which alters the fundamental arrangement of the atoms in a molecule without adding or removing anything from the original material. In the petroleum industry, straight-chain hydrocarbons are converted catalytically to branched-chain hydrocarbons of substantially higher octane number by isomerization.

KETTLE: 1. An open-top vessel used in carrying out metallurgical operations on low-melting-point metals; for example, in drossing and desilverizing lead.
2. An open or (usually) closed vessel for preparing paints, varnishes, and resins.

KILN: A furnace in which the heating operations do not involve fusion. Kilns are most frequently used for calcining, and free access of air is permitted. The raw materials may be heated by the combustion of solid fuel with which they are mixed, but more usually they are heated by gas or the waste heat from other furnaces.

KILN GAS: Hot effluent gases from a kiln. Unless controlled, these gases can be the largest source of particulates in a plant.

KISH: Variety of graphite occasionally formed in iron smelting furnaces.

KNOCKOUT DRUM: A drum or vessel constructed with baffles through which a mixture of gas and liquid is passed to disengage one from the other. As the mixture comes into contact with the baffles, the impact frees the gases and allows them to pass overhead; the heavier substance falls to the bottom of the drum.

LAPSE RATE: The decrease of temperature with altitude.

LAUNDER: A trough, channel or gutter usually of wood, by which water is conveyed. Specifically, in mining, a chute or trough for conveying powered ore, or for carrying water to or from the crushing apparatus.

LEACHING: Extracting a soluble metallic compound from an ore by selectively dissolving it in a suitable solvent, such as water, sulphuric acid, hydrochloric acid, etc.

LEAD: Pb. (Plumbum.) Element. Atomic weight 207.19
Atomic number 82. Soft, bluish-white metal. Occurs
chiefly as galena, PbS. Extracted by roasting the ore in
a reverberatory furnace. Compounds are poisonous.
Metal is used in the lead accumulator, in alloys, and
in plumbing; compounds are used in paint manufacture.

LIGNITE: Brown coal. Brownish-black, natural deposit
resembling coal. Contains a higher percentage of
hydrocarbons than ordinary coal, and of more recent origin.
Usually high in moisture and low in Btu's.

LUQUEFACTION OF GASES: A gas possessing a critical
temperature above room temperature may be liquified
merely by increasing the pressure on it. Otherwise the
gas must first be cooled to below its critical temper-
ature and then compressed; or, if desired, cooled
directly to its boiling point under normal pressure.
The methods of cooling are (1) by evaporation under
reduced pressure, as in the cascade liquifier;
(2) by using the principle of the Joule-Thomson effect
(the Linde process); (3) by causing the gas to expand
against an external pressure; in so doing the gas does
work, thereby cooling itself. This principle is used
in the Claude process.

LOUDNESS OF SOUND: The magnitude of the physiological
response of the ear to sound. As the ear responds
differently to different frequencies, the loudness of
a sound will depend to a certain extent on its frequency.
However, loudness can be roughly correlated with the
cube root of the intensity of sound, and different
levels can be conveniently compared by the units
decibel and phon.

MAGNETOHYDRODYNAMICS: MHD. A method of generating
electricity by subjecting the free electrons in a high
velocity flame or plasma to a strong magnetic field.
The free electron concentration in the flame is increased
by the thermal ionization of added substances of low
ionization potential (e.g. containing sodium or potassium).
These electrons constitute a current when they flow
between electrodes within the flame, under the influence
of the external magnetic field. It is hoped to use MHD
to increase the overall efficiency of conventional
power stations, by extracting a certain amount of energy
in this way from the flame that is used to raise steam
from the turbo-generators.

MANIFOLD: A pipe or header for collecting a fluid or
gas from, or distributing a fluid or gas to, a number
of pipes or tubes.

MANUFACTURED GAS: Fuel gas manufactured from coal, oil,
etc., as differentiated from natural gas.

MATERIAL BALANCE: An accounting of the weights of
material entering and leaving a process.

MATTE: A metallic sulphide mixture formed in smelting sulphide ores of copper, lead, and nickel.

MECHANICAL, CENTRIFUGAL SEPARATORS: A device for separating particulates. A rotating fan blade exerts a large centrifugal force on the particulates, ejecting them from the tips of the blades to a skimmer bypass leading into a dust hopper.

MECHANICAL SCRUBBER: A scrubber in which the water spray is generated by a rotating element or disc (see also scrubber).

MECHANICAL TURBULENCE: In meteorology, the induced eddy structure of the atmosphere due to the roughness of the surface over which the air is passing. The height and spacing of the elements causing the roughness will affect the turbulence.

MERCAPTANS: Thio-alcohols. Organic compounds with the general formula R.SH. Ethyl mercaptan C_2H_5SH , is a liquid used in the manufacture of rubber accelerators (b.p. $35^{\circ}C$).

MERCURY: Quicksilver, Hydrargyrum. Element, Hg, Atomic weight 200.59. Atomic number 80. Liquid, silvery-white metal. Occurs as cinnebar, HgS . Extracted by roasting the ore in a current of air. Used in thermometers, barometers, manometers, and other scientific apparatus; alloys (called amalgams) used in dentistry. Compounds are poisonous; some are used in medicine.

MESH: The number of holes per linear unit in a sieve or gauze, or the space between the wires of the sieve, expressed in inches or millimetres.

METEOROLOGY: The science of the weather. the study of such conditions as atmospheric pressure, temperature, wind strength, humidity, etc., from which conclusions as to the forthcoming weather are drawn.

METHANE: Marsh gas, fire-damp, CH_4 . First hydrocarbon of the paraffin series. Odourless, invisible gas, b.p. $-161.5^{\circ}C$. Inflammable, forms an explosive mixture with air. Formed from decaying organic matter and in coalmines; occurs in coal-gas.

METRIC TON: 2204.6 pounds or 1000 kilograms.

MICROMETRE: One-millionth of a metre (see Micron)

MICRON: One-millionth of a metre, μ , 10,000 Angstrom units.

MISCIBLE: Capable of being mixed to form a homogeneous substance; usually applied to liquids. e.g. water and alcohol are completely miscible.

MIST: Droplets of water, formed by the condensation of water-vapour on dust particles; a suspension of any finely divided liquid in a gas.

MODIFIED COAL: Coal of a stoker size containing a controlled percentage of fines.

MOLECULE: Smallest portion of a substance capable of existing independently and retaining the properties of the original substance.

MULTICYCLONE (ALSO MULTIPLE CYCLONE OR MULTICLONE): A dust collector consisting of a number of cyclones operating in parallel, through which the volume and velocity of gas can be regulated by means of dampers to maintain dust-collector efficiency over the load range.

MULTIPLE-CHAMBER INCINERATOR: Any incinerator consisting of a primary combustion chamber, mixing chamber, and secondary combustion chamber in series. The chambers are separated by refractory walls, and interconnected by gas passage ports.

MULTIPLE-HEARTH TYPE ROASTER: See roasting furnace.

MUNICIPAL INCINERATOR: An incinerator owned or operated by a government or by a person who provides incinerator service to government or others; a device designed for and used to burn waste materials of any and all types.

NATURAL GAS: Gaseous forms of petroleum occurring in nature and used directly as a fuel. Natural gas consists of mixtures of hydrocarbon gases and vapours, the most important of which are methane, ethane, propane, and butane.

NECROSIS: Collapse and death of tissue.

NICKEL: Ni. Element. Atomic weight 58.71, atomic number 28. Silverywhite magnetic metal resembling iron. m.p. 1455°C. Resists corrosion. Occurs combined with sulphur or arsenic in pentlandite, kupfer-nickel, smaltite and other ores. The ore is roasted to form the oxide, which is reduced to the metal by hydrogen, and the metal is then purified by the Mond process. Used for nickel-plating in coinage, for alloys such as nickel steel, nickel-silver, platinoid, constantan, nichrome, and as a catalyst.

NICKEL PLATING: Depositing a thin layer of metallic nickel by an electrolytic process.

NITRIC ACID: Aqua fortis, HNO_3 . Colourless, corrosive acid liquid, b.p. 86°C. Powerful oxidizing agent. Attacks most metals and many other substances with evolution of brown fumes of nitrogen dioxide, NO_2 . Manufactured by the action of concentrated sulphuric acid, H_2SO_4 , on sodium or potassium nitrate, and by the oxidation of ammonia, NH_3 , by passing a mixture of ammonia and air over heated platinum which acts as a catalyst. Widely used in the chemical industry.

NITRIC OXIDE: NO. Colourless gas, reacts with oxygen on contact to form nitrogen dioxide, NO_2 .

NITROGEN OXIDES: A general term pertaining to a mixture of nitric oxide (NO) and nitrogen dioxide (NO_2).

NUCLEUS: Vital central point; particle of matter acting as centre; e.g. a particle of dust will act as a nucleus for the condensation of water vapour in mist.

OCTANE NUMBER OF A FUEL: Defined as the percentage by volume of iso-octane, C_8H_{18} , (2:2:4-trimethylpentane) in a mixture of iso-octane and normal heptane, C_7H_{16} , which is equal to the fuel in knock characteristics under specified test conditions.

ODORANT: A gaseous nuisance that is offensive or objectionable to the smell.

ODOUR: Substance that stimulates the olfactory organ, causing the sensation we call "smell".

Malodours: An odour which is considered unpleasant by most humans.

ODOUR INTENSITY: The numerical or verbal indication of the strength of an odour.

ODOUR PERVASIVENESS: The ability of an odour to diffuse into a large volume of air and still continue to possess a detectable intensity. A pervasive odour is one whose odour intensity changes very little on dilution.

ODOUR QUALITY: A verbal description of an odour. The quality may be described in terms of such familiar odorants as coffee, onions, lemons, or by associating an unfamiliar odour with a familiar odour.

ODOUR THRESHOLD: The lowest concentration of an odour in air that can be detected by a human.

ODOUR UNITS: That quantity of odour necessary to contaminate one cubic foot of air to threshold or barely perceptible level. The number of odour units is equal to the volume (scf) of air necessary to dilute the concentration of odorant in one volume (scf) of air to the threshold concentration.

OIL BURNER: Any device for the introduction of vaporized or atomized fuel oil into a furnace.

OIL-EFFLUENT WATER SEPARATOR: Any tank, box, sump, or other container in which any petroleum product entrained in water is physically separated and removed prior to out-fall, drainage, or recovery of the water.

OLEORESIN: A varnish or paint vehicle, made of plant oils and resins, usually cooked.

OLEUM (FUMING SULPHURIC ACID): A heavy, oily, strongly corrosive liquid that consists of a solution of sulphur trioxide in anhydrous sulphuric acid. It fumes in moist air and reacts violently with water.

OLFACtORY: Pertaining to the sense of smell.

ONSTREAM TIME: The length of time a unit is in actual production.

OPACITY: The degree to which emissions reduce the transmission of light and obscure the view of a distant object; the extent to which a medium is opaque. Numerically the reciprocal of the transmittance.

OPEN BURNING: The burning of any matter in such a manner that the products of combustion are emitted directly into the ambient air without passing through a stack, duct, or chimney.

OPEN HEARTH FURNACE: Reverberatory furnace, containing a basin-shaped hearth, for melting and refining suitable types of pig iron, iron ore, and scrap for steel production.

OPEN-HEARTH PROCESS: Siemens-Martin process. Process for steel manufacture. Pig-iron and steel scrap or iron ore in calculated amounts are heated together by producer gas on a hearth in a furnace.

ORE AND LIME BOIL: Reactions which occur in an open hearth furnace when carbon monoxide is produced by the oxidation of carbon. Ore boil is a violent agitation of the metal as it escapes during this process; lime boil occurs when the limestone decomposes and the carbon dioxide gas escapes. The second reaction begins before the first is completed.

ORGANIC SULPHUR: The difference between the total sulphur in coal and the sum of the pyritic sulphur and sulphate sulphur.

ORGANOLEPTIC: Affecting or making an impression upon one or more of the sense organs.

ORIFICE SCRUBBERS: Devices for the removal of particulates from gas streams in which the flow of air through a restricted passage partially filled with water causes the dispersion of the water and consequent wetting and collection of the particulates.

ORSAT APPARATUS: A portable apparatus for determining the amount of carbon dioxide, oxygen, and carbon monoxide in flue or exhaust gases. A measured volume of the gas is successively passed through three tubes, the first of which contains potassium hydroxide to absorb the CO₂, the second alkaline pyrogallol to absorb oxygen, and the third cuprous chloride in hydrochloric acid to absorb the CO. The diminution of volume after the gas has been passed through each tube indicates the quantity of each constituent gas.

OSMOSIS: The flow of water (or other solvent) through a semi-permeable membrane which will permit the passage of the solvent but not of dissolved substances. There is a tendency for solutions separated by such a membrane to become equal in molecular concentration; thus water will flow from a weaker to a stronger solution, the solutions tending to become more nearly equal in concentration.

OSMOTIC PRESSURE OF A SOLUTION: The pressure which must be applied to a solution in order to prevent the flow of solvent through a semi-permeable membrane separating the solution and the pure solvent. When a solvent is allowed to flow through such a membrane into a vessel or cell containing a solution, the solvent will flow into the cell (see osmosis) until such a pressure is set up as to balance the pressure of the solvent flowing in. The osmotic pressure of a dilute solution is analogous to gaseous pressure; a substance in solution, if not dissociated, exerts the same osmotic pressure as the gaseous pressure it would exert if it were a gas at the same temperature, and occupying the same volume. The osmotic pressure, temperature, and volume of a dilute solution of a non-electrolyte are connected by laws exactly similar to the gas laws.

OVERBURDEN: Material of any nature, consolidated or unconsolidated, that overlies a deposit of useful material, ores or coal, especially those deposits that are mined from the surface by open cuts.

OVERFIRE: Air for combustion admitted into the furnace at a point above the fuel bed.

OXIDANTS: Those substances in the air (such as ozone, PAN, and nitrogen dioxide) which are capable of oxidizing other chemicals or elements in oxidation-reduction type chemical reactions. Oxidants are made up mostly of ozone, and only small amounts of the other materials.

OXIDATION: The combination of oxygen with a substance, or the removal of hydrogen from it. The term is also used more generally to include any reaction in which an atom loses electrons: e.g., the change of a ferrous ion, Fe⁺⁺, to a ferric ion, Fe⁺⁺⁺.

OXIDIZING AGENT: A substance which brings about an oxidation reaction.

OXYGEN LANCING: In steel making, a procedure in which oxygen is injected into the bath of molten metal through a water cooled lance. The oxygen oxidizes carbon, silicon, manganese, and some iron in exo-thermic reactions. The procedure materially shortens the time needed to tap the furnace.

PACKED COLUMN (PACKED SCRUBBER OR PACKED TOWER): A vertical column used for distillation, absorption, and extraction, containing packing; e.g., Raschig rings, Berl saddles, or crushed rock, which provide a large contacting surface area between phases. Normally, gas flow is countercurrent to liquid flow.

PAN: Peroxyacetyl nitrates. Secondary pollutants formed in photochemical oxidation and major eye irritants of photochemical smog.

PARTICLE CONCENTRATION: Concentration expressed in terms of number of particles per unit volume of air or other gas.

PARTICULATE MATTER: Any dispersed matter, solid or liquid, in which the individual aggregates are larger than single small molecules (0.0002 micrometres) but smaller than 500 micrometres.

PATHOGENIC: Causing disease.

PEAT: Early stage in the formation of coal from vegetable matter. Accumulation of partially decomposed plant material, used as fuel.

PERCOLATOR: A device used in rendering plants for the separation of dry proteinaceous crackling from the clear moisture-free tallow. They are generally perforated pans which allow the tallow to drain away from the cracklings.

PERFORMANCE TEST: Measurement of emissions used for the purpose of determining compliance with a standard of performance.

PETROCHEMICAL INDUSTRY: A branch of the petroleum industry in which refined crude oil is manufactured into various chemicals.

PETROLEUM COKE: See coke, petroleum.

PH VALUE: See hydrogen ion concentration.

PHENOLS: Class of aromatic organic compounds containing one or more hydroxyl groups attached directly to the benzene ring. They correspond to the alcohols in the aliphatic series, forming esters and ethers, but they also have weak acidic properties and form salts.

PHON: A unit of loudness, used in measuring the intensity of sounds. The loudness, in phons, of any sound is equal to the intensity in decibels of a sound of frequency 1000 which seems as loud to the ear as the given sound.

PHOTOCHEMICAL REACTIONS: Chemical reactions occurring in the atmosphere under the influence of sunlight. The energy for these reactions is obtained from sunlight, particularly the ultraviolet rays. The results of these reactions are photochemical smogs.

PHOTOSYNTHESIS: The process by which green plants manufacture their carbohydrates from atmospheric carbon dioxide and water in the presence of sunlight. The reaction, which is highly complex in detail, may be summarized by the equation:



When light falls upon green plants the greatest part of the energy is absorbed by small particles called chloroplasts, which contain a variety of pigments, among them compounds call chlorophylls. The chlorophylls transform the energy of the light into chemical energy by a process which is not fully understood, but which is known to involve the photolysis of water and the activation of adenosine triphosphate (ATP). The energy-rich ATP subsequently energizes the fixation of the CO₂, after a series of reactions, so that sugar molecules are formed. As animals are unable to fix atmospheric CO₂ in this way, they depend for their carbon on the plants (or other animals) which they consume. Photosynthesis is therefore essential to all the higher life forms, directly or indirectly.

PHYTOTOXIC: POISONOUS to plants.

PLUME: The flow of visible effluent from a specific outlet, such as a stack or vent.

POINT SOURCE: Any stationary emitting point or plant/facility whose summation of emitting points totals 100 tons (or some other fixed amount) per year of any pollutant in a given region.

POLYCYCLIC MOLECULE: A molecule containing two or more fixed rings (as in anthracene).

POLYMER: Product of polymerization.

POLYMERIZATION: 1. A reaction combining two or more molecules to form a single molecule having the same elements in the same proportions as in the original molecules. 2. The union of light olefins to form hydrocarbons of higher molecular weight. The process may be thermal or catalytic.

POLYNUCLEAR AROMATIC HYDROCARBONS: Compounds consisting of two or more aromatic rings which share a pair of carbon atoms. The simplest and most important is naphthalene ($C_{10}H_8$: also polycyclic).

POLYVINYL CHLORIDE: PVC. A colourless thermoplastic material, produced by the polymerization of vinyl chloride, with good resistance to water, acids, alkalis, and alcohols.

PRECLEANERS: Collectors of limited efficiency used ahead of the final cleaner. If the gas contains an appreciable amount of hard, coarse particles, a precleaner can materially reduce erosive wear of the more efficient final collector.

PRECURSORS: Gaseous air pollutants which react with other substances in the atmosphere to produce different pollutants; e.g., photochemical reactions of NO and NO_2 with the oxygen of the air which produce ozone.

PRILLING: A combination spray drying and crystallization technique used in the production of ammonium nitrate. A hot ammonium nitrate solution is sprayed in the top of a tower, and air is blown in at the bottom. The liquid is converted into spherical pellets.

PRIMARY AIR: The air which is first introduced to the fuel in the process of combustion. See secondary air.

PRIMARY EMISSION: Pollutants emitted directly into the air from identifiable sources.

PROCESS WEIGHT: The total weight of all materials introduced into a source operation, including solid fuels, but excluding liquids and gases used solely as fuels, and excluding air introduced for purposes of combustion.

PRODUCER GAS: A fuel gas produced by the partial combustion of coke and coal in a restricted supply of air, to which steam may have been added. The principal constituents of the gas are carbon monoxide (25% - 30%), nitrogen (50% - 55%), and hydrogen (10% - 15%). Hydrocarbons and carbon dioxide will also be present.

PUDDLING PROCESS: Preparation of nearly pure wrought iron from cast iron which contains a high percentage of carbon. The cast iron is heated with haematite, Fe_2O_3 , the oxygen in which oxidizes the carbon.

PUG MILL: A machine for mixing water and clay which consists of a long horizontal barrel within which is a long longitudinal shaft fitted with knives which slice through the clay, mixing it with water which is added by sprayers from the top. The knives are canted to give some screw action, forcing the clay along the barrel and out one end.

PUMP, RECIPROCATING: A positive-displacement type of pump consisting of a plunger or a piston moving back and forth within a cylinder. With each stroke of the plunger or piston, a definite volume of liquid is pushed out through the discharge valves.

PYRITIC SULPHUR: Sulphur combined with iron, found in coal.

PYROLYSIS: Chemical change brought about by the action of heat upon a substance.

PYROMETER: An instrument for measuring temperatures beyond the range of thermometers.

RANKINE SCALE OF TEMPERATURE: $^{\circ}\text{R}$. The absolute Fahrenheit scale. Zero degrees Rankine is -459.69°F . and therefore $^{\circ}\text{F} + 459.69 = ^{\circ}\text{R}$.

RAREFACTION: A reduction in pressure. The opposite of compression.

RECOVERY BOILER: In wood pulping, a combustion unit designed to recover the spent chemicals from the cooking liquor and to produce steam for pulping and recovery operations.

RED LEAD: Minimum. Pb_3O_4 . Bright scarlet powder, used as a pigment in glass manufacture and as an oxidizing agent.

REDUCTION: The removal of oxygen from a substance, or the addition of hydrogen to it. The term is also used more generally to include any reaction in which an atom gains electrons.

REFINERY GAS: Any form or mixture of still gas gathered in a refinery from the various stills.

REFINING: In metallurgy, the removal of impurities necessary to produce an ingot or metal alloy of desired specification. In petroleum, the process of separating, combining, or rearranging petroleum oil constituents to produce saleable products.

REFORMING: The thermal or catalytic conversion of naptha into more volatile products of higher octane number. It represents the total effect of numerous reactions, such as cracking, polymerization, dehydrogenation, and isomerization, taking place simultaneously.

REFRACTORY: A ceramic material of very high melting point with properties that make it suitable for such uses as furnace and kiln linings.

RELATIVE HUMIDITY: Hygrometric state of the atmosphere. Can be defined either as (1) the ratio of the pressure of the water vapour actually present in the atmosphere to the pressure of the vapour which would be present if the vapour were saturated at the same temperature; or (2) the ratio of the mass of water vapour per unit volume of the air to the mass of water vapour per unit volume of saturated air at the same temperature. The numerical difference between the two is very small and can normally be neglected. The relative humidity is usually expressed as a percentage. Its value may be determined from a knowledge of the dew-point, since the saturated vapour pressure at the dew-point is equal to the aqueous vapour pressure at the temperature of the experiment. The result is then obtained by reference to tables which give the saturated vapour pressure at different temperatures.

RERUN OIL: Oil which has been redistilled.

RESIDUAL: Heavy oil left in the still after gasoline and other distillates have been distilled off, or residue from the crude oil after distilling off all but the heaviest components.

RESISTIVITY: The property of a body whereby it opposes and limits the passage of electricity through it. Resistivity of dust is an important factor in the performance of electrostatic precipitators. If the resistivity of the collected dust is higher than about 2×10^{18} ohm-cm, excessive arcing or reverse corona can occur, thereby limiting precipitator performance.

RETORT: A glass vessel consisting of a large bulb with a long neck narrowing somewhat towards the end. In industrial processes, any vessel from which distillation takes place; in the canning industry, a large autoclave for heating sealed cans by superheated steam under pressure.

REVERBERATORY FURNACE: A furnace with a shallow hearth; having a roof that deflects the flame and radiates heat towards the surface of the charge. Furnace designed for operations in which it is not desirable to mix the material with the fuel; the roof is heated by flames, and the heat is radiated down on to the material off the roof. Firing may be with coal, pulverized coal, oil or gas.

RINGELMANN CHART: It consists of four, five and three-quarter by eight and one-half inch charts, each with a rectangular grid of black lines on a white background. The width and spacing of the lines are designed so that each chart presents a certain percentage of black. Ringelmann #1 is equivalent to 20% black; Ringelmann #2, 40% black; Ringelmann #3, 60% black; Ringelmann #4, 80% black; Ringelmann #5, which is not part of the chart, is 100% black. It is used to evaluate the degree of blackness of smoke plumes.

ROAST: To heat to a point somewhat short of fusing, with access to air, so as to expel volatile matter or effect oxidation. In copper metallurgy, applied specifically to the final heating which causes self-reduction to occur by the reaction between the sulphide and the oxide.

ROASTER: 1. A contrivance for roasting, or a furnace for drying salt cake. 2. A reverberatory furnace or a muffle used in roasting ore.

ROASTING: 1. Heating an ore to effect some chemical change that will facilitate smelting. 2. The heating of solids, frequently to promote a reaction with a gaseous constituent in the furnace atmosphere.

ROASTING FURNACE: A furnace in which finely ground ores and concentrates are roasted to eliminate sulphur; heat is provided by the burning sulphur.

RUN OF MINE COAL: Unscreened bituminous coal as it comes from the mine.

SALAMANDER: A small portable incinerator, or a small portable heater burning coke or oil.

SALT: Chemical compound formed when the hydrogen of an acid has been replaced by a metal. A salt is produced, together with water, when an acid reacts with a base. Salts are named according to the acid and the metal from which the salt is derived; thus copper sulphate is a salt derived from copper and sulphuric acid.

SCRUBBER: A device used to remove entrained liquids and solids from a gas stream by passing the gas through wetted "packing" or spray. See absorber.

SECONDARY AIR: Air introduced into a combustion chamber beyond the point of fuel and primary air introduction for the purpose of achieving more complete oxidation.

SEMI-PERMEABLE MEMBRANE: A membrane allowing the passage of some substances and not of others; a partition which permits the passage of pure solvent molecules more readily than those of the dissolved substance. e.g., copper ferrocyanide, $Cu_2Fe(CN)_6$, is permeable to water, but only very slightly permeable to dissolved substances. Used as a partition between solution and solvent in osmotic measurements and in dialysis.

SHERARDIZING: A method of plating iron or steel with zinc, to form a corrosion resistant coating. The iron or steel is heated in contact with zinc powder to a temperature slightly below the melting point of zinc. At this temperature the two metals amalgamate forming internal layers of zinc-iron alloys and an external layer of pure zinc.

SINTERING: Compressing metal particles into a coherent solid body. The process is carried out under heat, but at a temperature below the melting point of the metal. Certain non-metals such as ceramic and glass may also be sintered.

SKIMMING PLANT: An oil refinery designed to remove and finish only the lighter constituents from the crude oil, such as gasoline and kerosene. In such a plant the portion of the crude remaining after the above products are removed is usually sold as fuel oil.

SKIP HOIST, INCLINED: A bucket or can operating up and down, receiving, elevating, and discharging bulk materials.

SLAG: The non-metallic top layer which separates from the metallic products in the smelting of ores. Generally formed as a molten mass floating on the molten metal.

SLOP OR SLOP OIL: A term rather loosely used to denote odds and ends of oil produced at various places in a plant, which must be rerun or further processed in order to be made suitable for use. When good for nothing else, such oil usually goes into pressure-still charging stock, or to coke stills.

SMELT: In wood pulping, the molten chemicals from the kraft recovery furnace consisting mostly of sodium sulphide and sodium carbonate.

SMELTING: Any metallurgical operation in which metal is separated by fusion from impurities with which it may be chemically combined or physically mixed, such as in ores. Generally the process is one of chemical reduction of the oxide of the metal with carbon in a suitable furnace.

SMOG: A term derived from a combination of the words "smoke" and "fog". It is used to characterize certain types of atmospheric pollution by aerosols. However, this term has not been given a precise definition.

London Smog: Condition occurring in cooler, foggy weather during periods of air stagnation in areas where coal is the principal space heating fuel. It is characterized by the high content of sulphur compounds, smoke and fly ash, and may produce extremely poor visibility, bronchial irritation, and has been known to cause death.

Photochemical Smog: A condition occurring in sunny, poorly ventilated, heavily-motorized urban areas. It is characterized by the interaction of oxides of nitrogen and hydrocarbons (one of the major sources of these is the automobile) under the influence of sunlight. May produce poor visibility, eye irritation, and damage to materials and vegetation.

SMOKE: Small gas-borne particles resulting from incomplete combustion, consisting predominantly but not exclusively of carbon, ash, and other combustible material, and present in sufficient quantity to be observable. Generally, a suspension of fine particles of a solid in a gas.

SMOKE CANDLE(S): Apparatus used in collecting acid mists. Tubes or candles made from glass or plastic fibres are pressed into pads with thicknesses up to 2 inches and mounted in banks. Efficiency is much increased when the glass is treated with silicone oil to repel water, or when normally water-repellent plastic is used.

SOILING: Visible damage to materials by deposition of air pollutants.

SOLDER: An alloy for joining metals. Soft solders are alloys of tin and lead in varying proportions; brazing solders are usually composed of copper and zinc.

SOLUTE: A substance which is dissolved in a solvent to form a solution.

SOLVENT: Substance (usually liquid) having the power of dissolving other substances in it; that component of a solution which has the same physical state as the solution itself. E.g., in a solution of sugar in water, water is the solvent, while sugar is the solute.

SOOT: Agglomerated particles consisting mainly of carbonaceous material, resulting from incomplete combustion.

SOUND: A physiological sensation received by the ear. It is caused by a vibrating source and transmitted as a longitudinal pressure wave motion through a medium such as air.

SOUND, VELOCITY OF: The velocity of propagation of sound waves. This velocity is a function of the temperature and of the nature of the propagating medium. In gases it is independent of the pressure. In air at 0°C it is 1120 feet or 332 metres per second, approximately 760 miles per hour.

SOUR: Gasolines, napthas, and refined oils are said to be "sour" if they show a positive "doctor test"; i.e., if they contain hydrogen sulphide and/or mercaptans. Sourness is directly connected with odour, while a "sweet" gasoline has a good odour.

SOURCE: Any property, real or personal, or person contributing to air pollution.

SOURCE SAMPLE: A sample of the emission from an air contamination source, collected for analysis from within a stack.

SPARK ARRESTOR: A screenlike device to prevent sparks, embers, and other ignited materials larger than a given size from being expelled to the atmosphere.

SPEISSL: Metallic arsenides and antimonides smelted from cobalt and lead ores.

SPONTANEOUS COMBUSTION: The combustion of a substance of low ignition point, which results from the heat produced within the substance by slow oxidation.

SPRAY CHAMBER: The simplest type of scrubber consisting of a chamber in which spray nozzles are placed. They are used extensively as gas coolers because they have a low collection efficiency for anything but coarse particles.

STABILITY (STATIC STABILITY): The state of the atmosphere when it is stable relative to vertical displacements.

STACK OR CHIMNEY: Any flue, conduit, or duct arranged to conduct an effluent to the open air.

STACK SPRAY: A nozzle or series of nozzles installed in a stack above the breeching, used to inject wetting agents at high pressure to suppress the discharge of particulate matter from the stack.

STANDARD CONDITIONS (SC): For source testing, 70° F (21.1° C) and 29.92" Hg (760 mm Hg); for air quality measurement, 77° F (25° C) and 29.92" Hg (760 mm Hg); for chemistry, 273.1 K (0° C) and one atmosphere (760 mm Hg); for petroleum refining, 60° F (15.55° C) and 14.7 psi (760 mm Hg).

STATIONARY SOURCE: Any non-mobile building, structure, facility, or installation which emits or may emit any air pollutant.

STEAM DISTILLATION: Introduction of "open" steam into the liquid during distillation to assist in vaporizing the volatiles at a lower temperature.

STILL: A closed chamber, usually cylindrical, in which heat is applied to a substance to change it into vapour, with or without chemical decomposition. The substance, in its vapour form, is conducted to some cooling apparatus where it is condensed, liquified, and collected in another part of the unit.

STOCK: In general, any oil which is to receive further treatment before going into finished products.

STOICHIOMETRIC: The exact quantity of reactants required to react according to a particular chemical equation. If the reaction were complete, only products and no reactants would remain.

STOKER: A machine for feeding coal into a furnace, and supporting it there during the period of combustion. It may also perform other functions, such as supply air, control combustion, or distill volatile matter. Modern stokers may be classified as overfeed, underfeed, and conveyor. Any mechanical device that feeds fuel uniformly onto a grate or hearth within a furnace may be termed a "stoker".

STOPING: In mining, any process of excavating ore which has been made accessible by shafts and drifts.

STP: Standard temperature and pressure of 0°C and 1 atmosphere. Values such as scfh (standard cubic feet per hour) are based on SC.

STRAIGHT-RUN DISTILLATION: Continuous distillation which separates the products of petroleum in the order of their boiling points without cracking.

STRIPPER: Equipment in which the lightest fractions are removed from a mixture. In a natural-gasoline plant, gasoline fractions are stripped from rich oil. In the distillation of crude petroleum, light fractions are stripped from the various products.

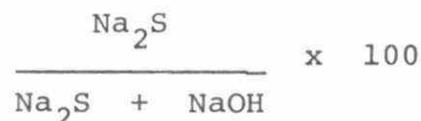
SUBLIMATE: Solid obtained by the direct condensation of a vaporized solid without passing through the liquid state.

SUBLIMATION: The conversion of a solid direct into vapour, and subsequent condensation, without melting.

SUBSTITUTION: A chemical reaction in which one or more atoms or groups of a molecule are replaced by equivalent atoms or groups to form at least two products, especially the replacement of hydrogen in an organic compound by another element or group.

SULPHIDE: A binary compound of an element or group with sulphur; a salt of hydrogen sulphide, H₂S.

SULPHIDITY: An expression of the percentage makeup of chemical kraft cooking liquor obtained by the formula:



where the sodium compounds are expressed as Na₂O.

SULPHUR: S. Element. Atomic number 16. Non-metallic element occurring in several allotropic forms. The stable form under ordinary conditions is rhombic or alpha-sulphur, a pale-yellow brittle crystalline solid.

Burns with a blue flame to give sulphur dioxide; combines with many metals to form sulphides. Occurs as the element in many volcanic regions and as sulphides of many metals. Used in the manufacture of sulphuric acid, carbon disulphide, for vulcanizing rubber, in the manufacture of dyes and various chemicals, for killing moulds and pests, and in medicine. Essential to life.

SULPHUR DIOXIDE: SO_2 . Colourless gas with a choking, penetrating smell; liquid SO_2 is used in refrigerators.

SULPHUR TRIOXIDE: SO_3 . White crystalline solid, m.p. 16.8°C. Combines with water to form sulphuric acid.

SULPHURIC ACID: Vitriol, oil of vitriol. Colourless, oily liquid. Extremely corrosive, reacts violently with water with evolution of heat, chars organic matter. Dibasic acid. Prepared by the lead chamber and the contact processes. Used extensively in many processes in chemical industry, and in the lead accumulator.

SUPERPHOSPHATE: Products obtained by mixing phosphate rock with either sulphuric or phosphoric acid, or both.

SURFACE CONDENSERS: A condenser in which the coolant does not contact the vapours or condensate. Most are of the tube and shell type. Water flows inside the tubes and vapours condense on the shell side.

SURFACE TENSION: An open surface of a liquid is under a state of tension, causing a tendency for the portions of the surface to separate from each other; the surface thus shows properties similar to those of a stretched elastic film over the liquid. The tension is an effect of the forces of attraction existing between the molecules of a liquid. Measured by the force per unit length acting on the surface at right angles to an element of any line drawn in the surface. A surface tension exists in any boundary surface of a liquid.

SURGE TANK: A storage reservoir at the downstream end of a feeder pipe to absorb sudden rises of pressure and to furnish liquid quickly during a drop in pressure.

SWEETENING: The process by which petroleum products are improved in odour and colour by oxidizing or removing the sulphur-containing and unsaturated compounds.

SYNERGISM: Co-operative action of discrete agents such that the total effect is greater than the sum of the two effects taken independently.

SYNTHETIC CRUDE: The total liquid, multi-component mixture resulting from a process involving molecular rearrangement of charge stock. Term commonly applied to the product from cracking, reforming, visbreaking, etc.

TAIL OIL: That portion of an oil which vaporizes near the end of the distillation; the heavy end.

TAIL GAS: The exhaust or waste gas from a process.

TALLOW: The rendered fat of animals that is white and almost tasteless when pure, composed of glycerides of fatty acids containing a large proportion of palmitic acid and stearic acid, and that is used chiefly in making soap, glycerol, margarine, candles, and lubricants.

TAPPING: Removing molten metal from a furnace.

TEKTITES: Small glass-like bodies whose chemical composition is unrelated to the geological formations in which they are found; believed to be associated with meteorites of extra-terrestrial origin. "Carbonaceous" tektites contain traces of carbon compounds.

TEMPERATURE INVERSION: An atmospheric layer in which temperature increases with altitude. The principal characteristic of a temperature inversion is its marked static stability, so that very little turbulent exchange can occur within it.

THEORETICAL AIR: The exact amount of air (stoichiometric air) required to supply the oxygen necessary for the complete combustion of a given quantity of a specific fuel or refuse.

THERM: Practical unit of quantity of heat; 100,000 British Thermal Units, 25,200,000 calories.

THERMAL TURBULENCE: Air movement and mixing caused by temperature differences.

THRESHOLD: The lowest value of any stimulus, signal, or agency which will produce a specified effect, e.g., threshold frequency.

TOPPED CRUDE PETROLEUM: A residual product remaining after the removal, by distillation, of an appreciable quantity of the more volatile components of crude petroleum.

TOPPING: The distillation of crude oil to remove light fractions only.

TOTAL REDUCED SULPHUR COMPOUNDS (TRS): Malodorous gases produced in the wood pulping industry exclusive of sulphur oxides. TRS usually includes hydrogen sulphide (H_2S), methyl mercaptan (CH_3SH), dimethyl sulphide (CH_3SCH_3), and dimethyl disulphide (CH_3SSCH_3). The concentration of TRS is usually expressed as H_2S regardless of the constituent compounds.

TOXICOLOGY: The study of poisons.

TURBULENCE: Atmospheric motions which produce a thorough horizontal and vertical mixing of the air.

TURNAROUND: The time between shutting down and starting up of process equipment for repair or maintenance.

TUYERES: Openings or nozzles in a metallurgical furnace through which air is blown as part of the extraction or refining process.

ULTIMATE ANALYSIS (OF COAL): Contains the following, expressed in percent by weight:

Carbon	(C)	%
Hydrogen	(H ₂)	%
Sulphur	(S)	%
Oxygen	(O ₂)	%
Nitrogen	(N ₂)	%
Ash		%
		100.0%

UNDERFEED STOKER: A stoker consisting of a trough or pot-shaped retort into which coal is forced by an endless screw or ram. Coal is fed to the fire zone by being pushed up from underneath.

UNIT OPERATION: 1. Methods by which raw materials may be altered into states, such as vapour, liquid or solid without being changed into new substances with different properties and composition. 2. Recognition, study, application and control of the principles and factors utilized in a distinct and self-contained process (for example, filtration). This avoids the duplication of effort which attends the study of similar processes as though each process involved a unique set of principles.

UNIT PROCESS: 1. Reactions where raw materials undergo chemical change. 2. See 'unit operation' (2).

UREA: Carbamide. CO(NH₂)₂. White, crystalline, organic compound, m.p. 132°C. Occurs in the urine. The first organic compound to be prepared artificially. Used as a fertilizer and in urea-formaldehyde resins.

UREA-FORMALDEHYDE RESINS: Thermosetting resins with good oil resistant properties, produced by the condensation polymerization of urea and formaldehyde.

UREA FORMS: A urea-formaldehyde reaction product that contains more than one molecule of urea per molecule of formaldehyde.

VACUUM DISTILLATION: The process of distillation carried out at a reduced pressure. The reduction in pressure is accompanied by a depression in the boiling point of the substance to be distilled, thus lower temperatures can be employed. This process, therefore, enables substances to be distilled which, at normal temperatures would decompose.

VACUUM JET (STEAM JET EJECTOR): A fluid nozzle that discharges a high velocity jet stream across a section chamber that is connected to the equipment to be evacuated. The gas in the chamber is entrained by the jet stream.

VAPOUR: The gaseous phase of a substance that generally exists as a liquid or solid at room temperature.

VAPOUR PLUME: The stack effluent consisting of flue gas made visible by condensed water droplets or mist.

VAPOUR RECOVERY SYSTEM: System used in petroleum refining for separating a mixed charge of miscellaneous gases and gasolines into desired intermediates for further processing.

VENTURI SCRUBBER: A type of high energy scrubber in which the waste gases pass through a tapered restriction (venturi) and impact with low-pressure water. Gas velocities at the restriction are from 15,000 to 20,000 fpm and pressure drops from 10 to 70 inches water gauge.

VISBREAKING: Viscosity breaking; lower or "breaking" the viscosity of residual oil by cracking at relatively low temperatures.

VISIBILITY: The greatest distance in a given direction at which it is just possible to see and identify with the unaided eye (a) in the daytime, a prominent dark object against the sky at the horizon, and (b) at night, a known, preferably unfocused, moderately intense light source. After visibilities have been determined around the entire horizon circle, they are resolved into a single value of prevailing visibility for reporting purposes.

VISCOSITY: The property of a fluid whereby it tends to resist relative motion within itself. If different layers of a fluid are moving with different velocities, viscous forces come into play, tending to slow down the faster-moving layers and to increase the velocity of the slower-moving layers. For two parallel layers in the direction of flow, a short distance apart, this viscous force is proportional to the velocity gradient between the layers. The constant of proportionality is called the coefficient of viscosity of the fluid. The C.G.S. unit of measurement of viscosity is the poise.

VOLATILE: Passing readily into a vapour; having a high vapour pressure.

VOLATILE OR VOLATILE MATTER: 1. The gasoline constituents that can be driven off liquids and solids by the application of heat. 2. Specifically for coal, that portion which is driven off in gas or vapour form when coal is subjected to a standardized temperature test.

VOLATILE ORGANIC COMPOUNDS: Any compound containing carbon and hydrogen in combination with any other element which has a vapour pressure of 1.5 pounds per square inch absolute or greater under actual storage conditions.

WASTE HEAT BOILERS: Boilers which utilize the heat of exhaust gas or process gas to generate steam or to heat water.

WEAK WASH: In wood pulping, a liquid stream in the kraft process which results from washing of the lime mud.

WEST COLLECTORS: Devices which use a variety of methods to wet the contaminant particles in order to remove them from the gas stream. See scrubbers.

WET FILTERS: A spray chamber with filter pads composed of glass fibres, knitted wire mesh, or other fibrous materials. The dust is collected on the filter pads.

WHITE LIQUOR: Cooking liquid used in the wood pulping industry. Kraft process: consists of approximately 1/3 sodium sulphide (Na_2S) and 2/3 sodium hydroxide (NaOH). Sulphite process: consists of sulphurous acid plus one of the following: calcium bisulphite, sodium bisulphite, magnesium bisulphite, or ammonium bisulphite.

WIND: A large-scale movement of air, generally caused by a convection effect in the atmosphere.

ZINC: Zn. Element. Atomic weight 65.37, atomic number 30. Hard, bluish-white metal, m.p. 419°C , b.p. 907°C . Occurs as calamine, ZnCO_3 , and zinc blende, ZnS . Extracted by roasting the ore to form the oxide, which is then reduced with carbon and the resulting zinc is distilled. Used in alloys, especially brass, and in galvanized iron.

ZINC OXIDE: ZnO . White amorphous powder, widely used as a pigment.